Jet Quenching and Initial Geometry/Conditions from the RHIC BES

Helen Caines - Yale University

BNL - April 2013

RHIC data available

Au-Au
200, 130, 62.4, 39, 27, 19.6,
11.5(STAR only), 7.7, 5(test run)

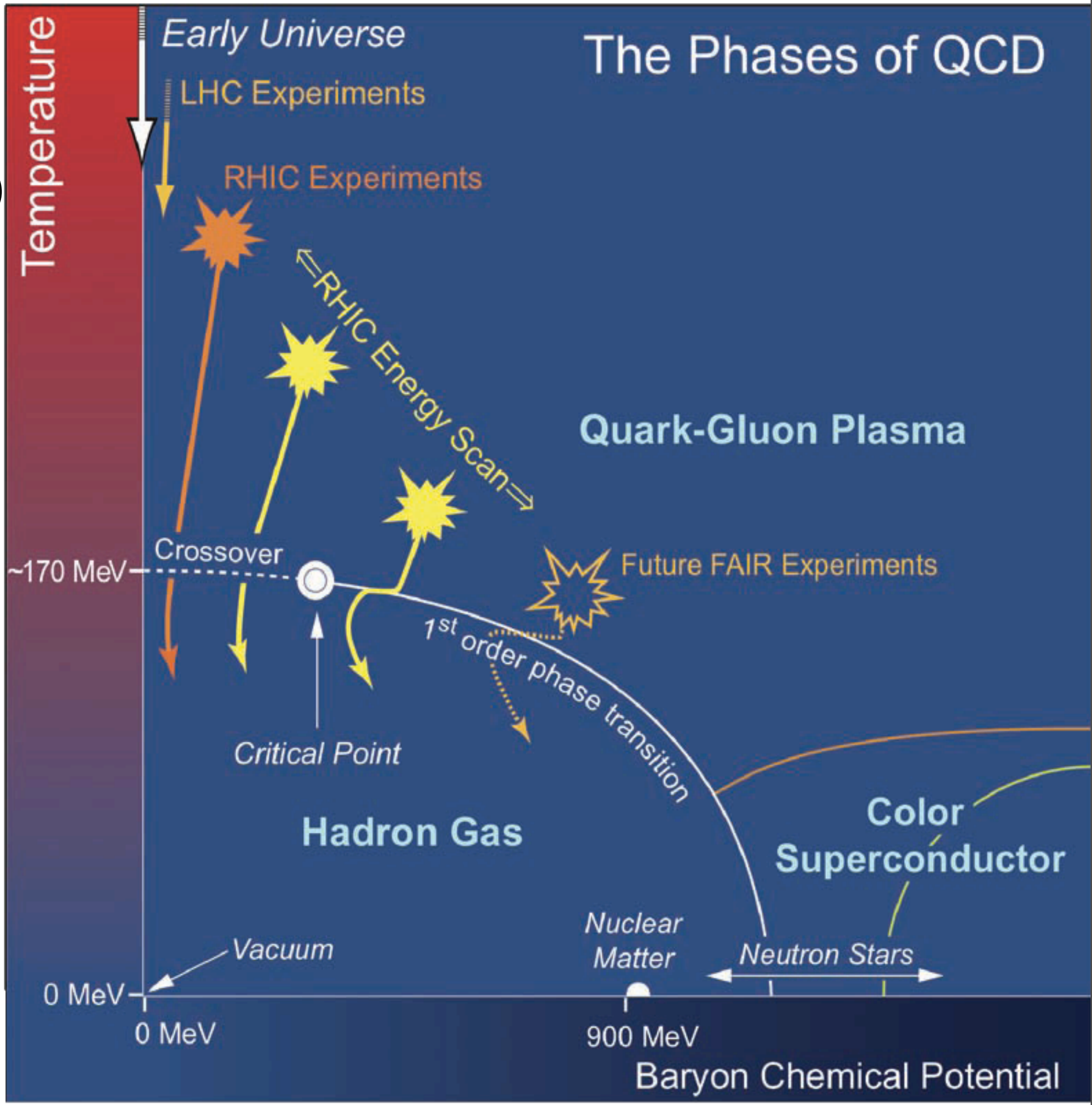
Cu-Cu
200, 62.4, 22.5

U-U
193

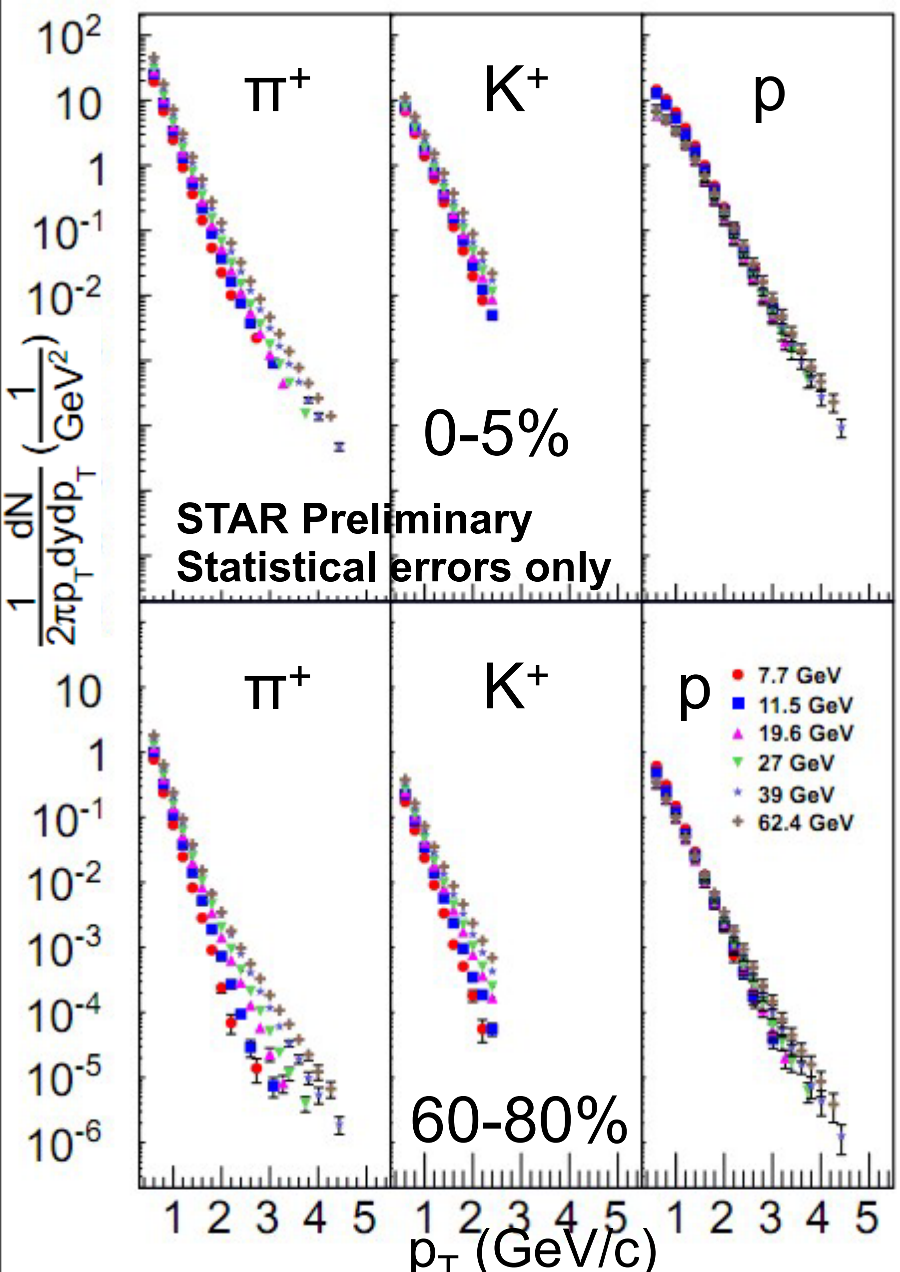
C-Au
200

p-p
200, 500

d-Au
200



Generic features of A-A collisions - I



Pion spectra:

Significant change in slope for peripheral data with collision energy

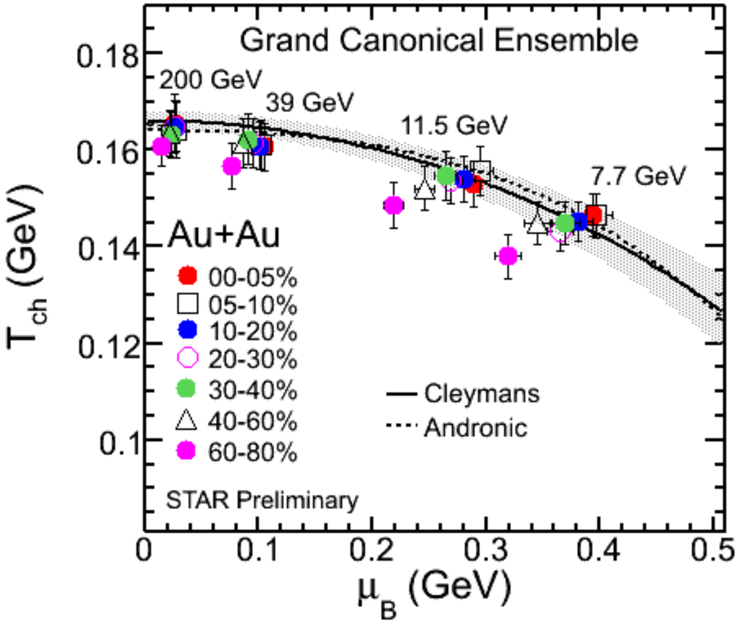
Proton spectra:

Little change with collision energy

Strong species dependence in spectra change

Horvat CPOD

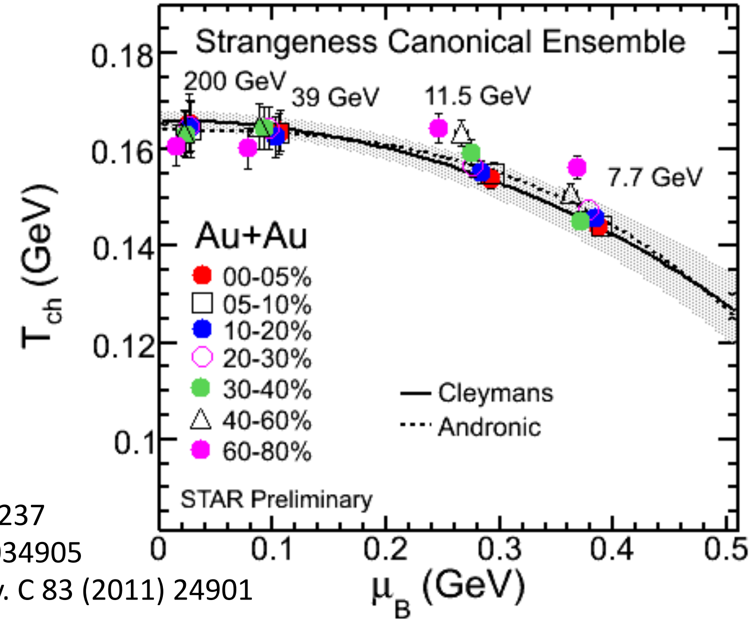
Generic features of A-A collisions - II



Particles used:
π, K, p, Λ, K^0_s, Ξ

THERMUS Model:
T_{ch} and μ_B

Chemical

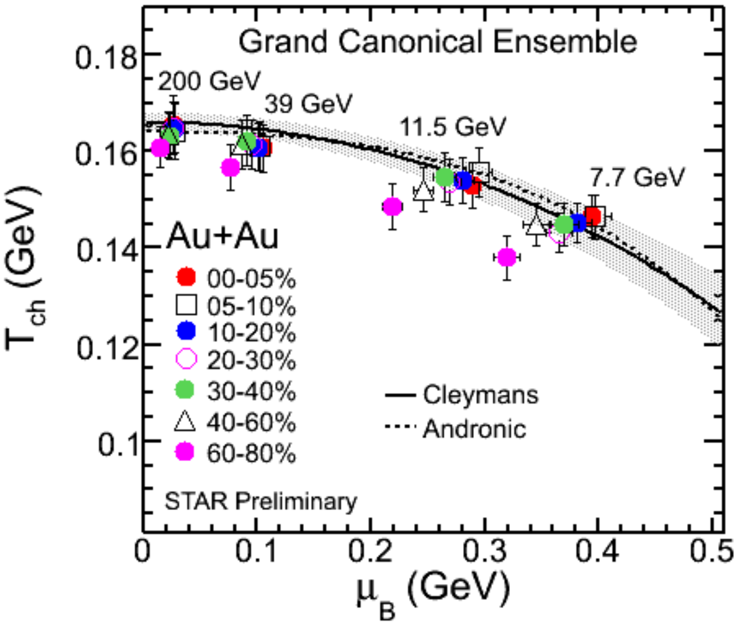


Andronic: NPA 834 (2010) 237
Cleymans: PRC 73 (2006) 034905
Au+Au 200 GeV : Phys. Rev. C 83 (2011) 24901

Opposite trends in centrality seen at lower energies for different ensembles

S. Das QM2012

Generic features of A-A collisions - II



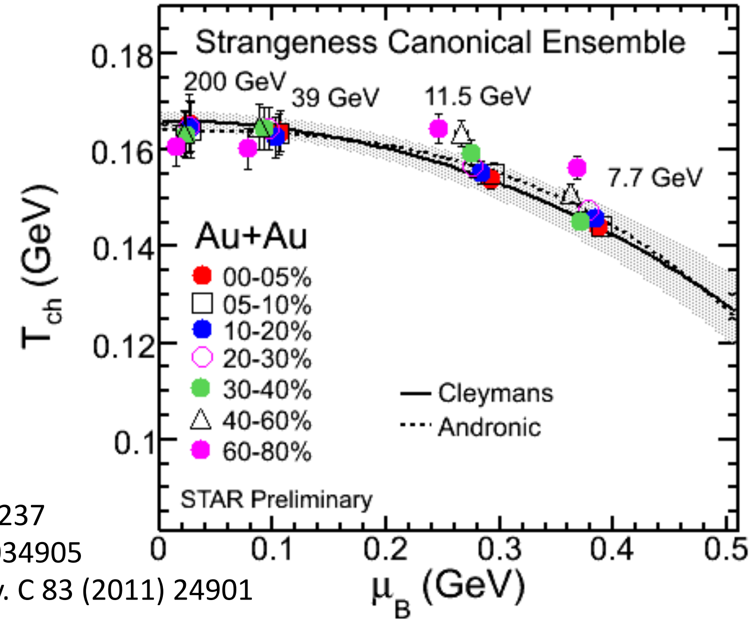
Particles used:

π, K, p, Λ, K^0_s, Ξ

THERMUS Model:

T_{ch} and μ_B

Chemical

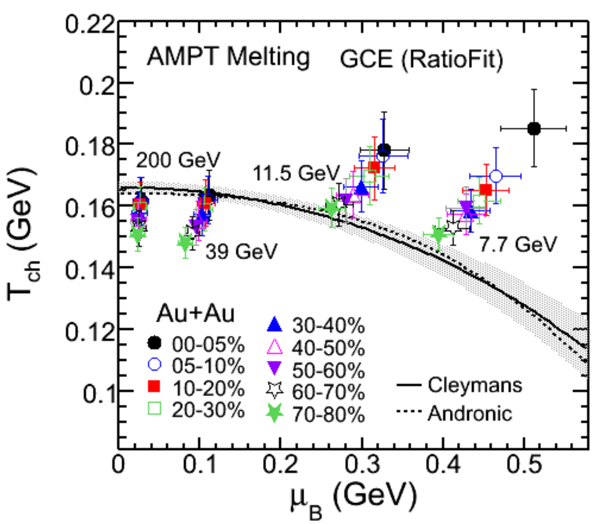


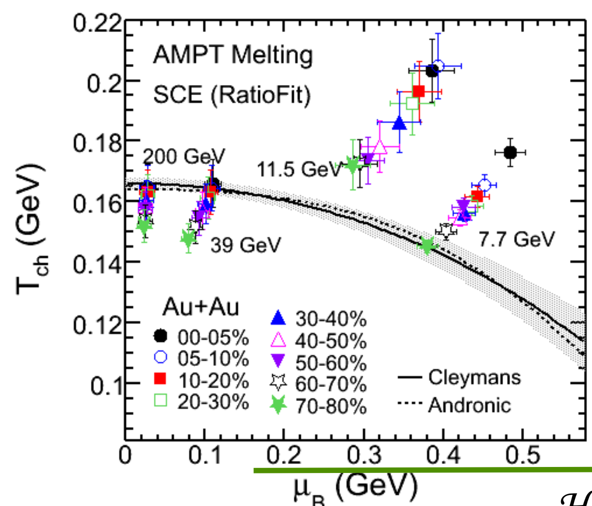
Andronic: NPA 834 (2010) 237

Cleymans: PRC 73 (2006) 034905

Au+Au 200 GeV : Phys. Rev. C 83 (2011) 24901

Opposite trends in centrality seen at lower energies for different ensembles

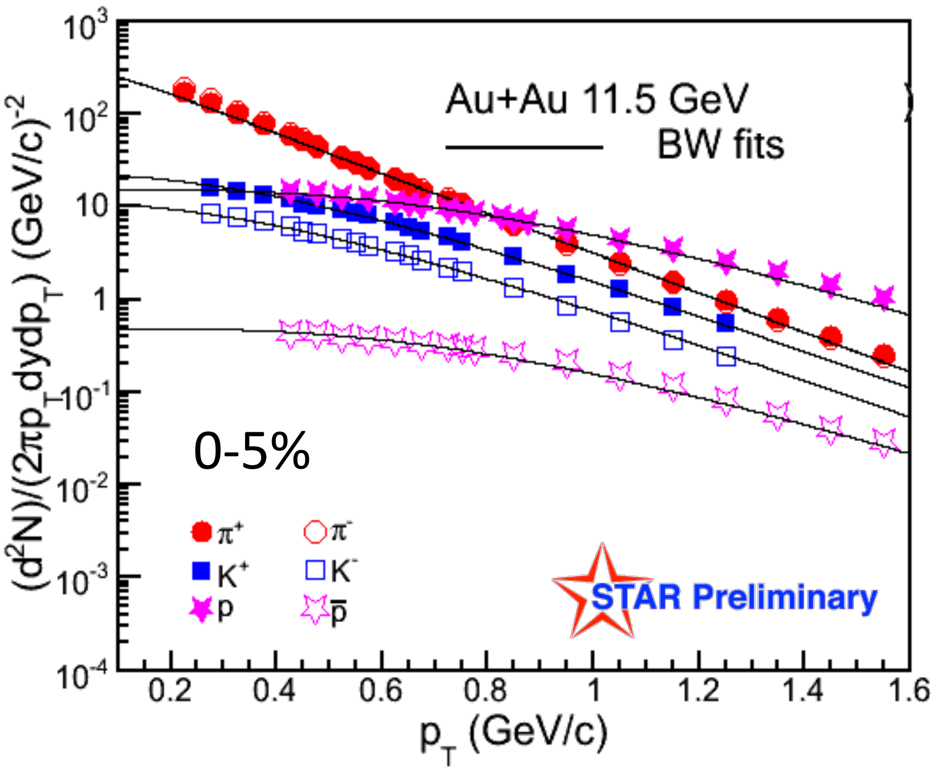


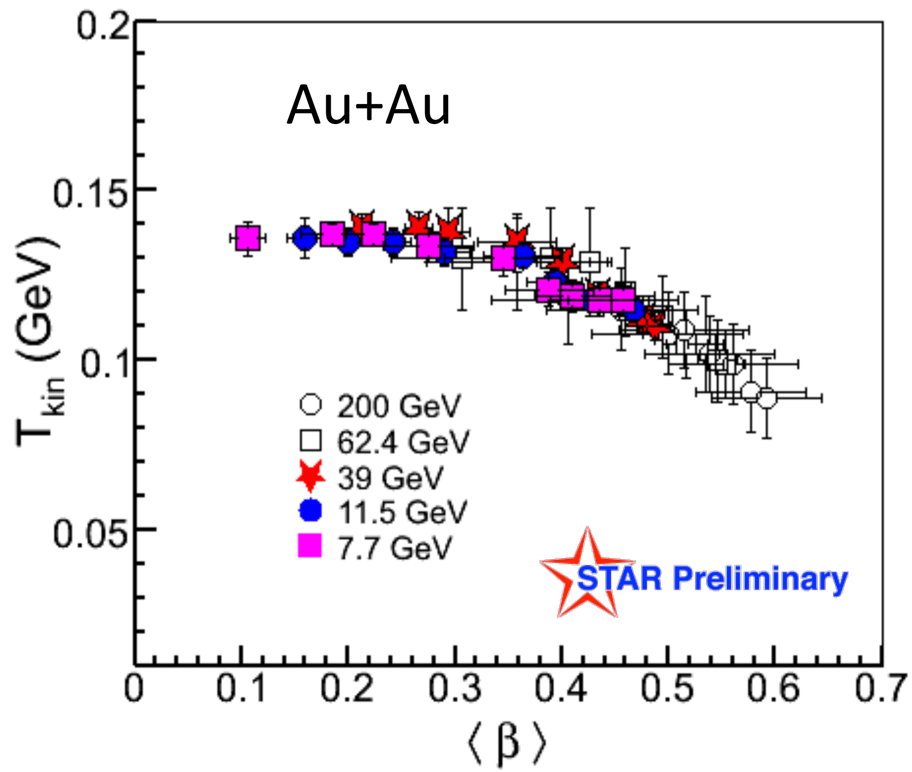


Not seen in simulations via AMPT

S. Das QM2012

Generic features of A-A collisions - III



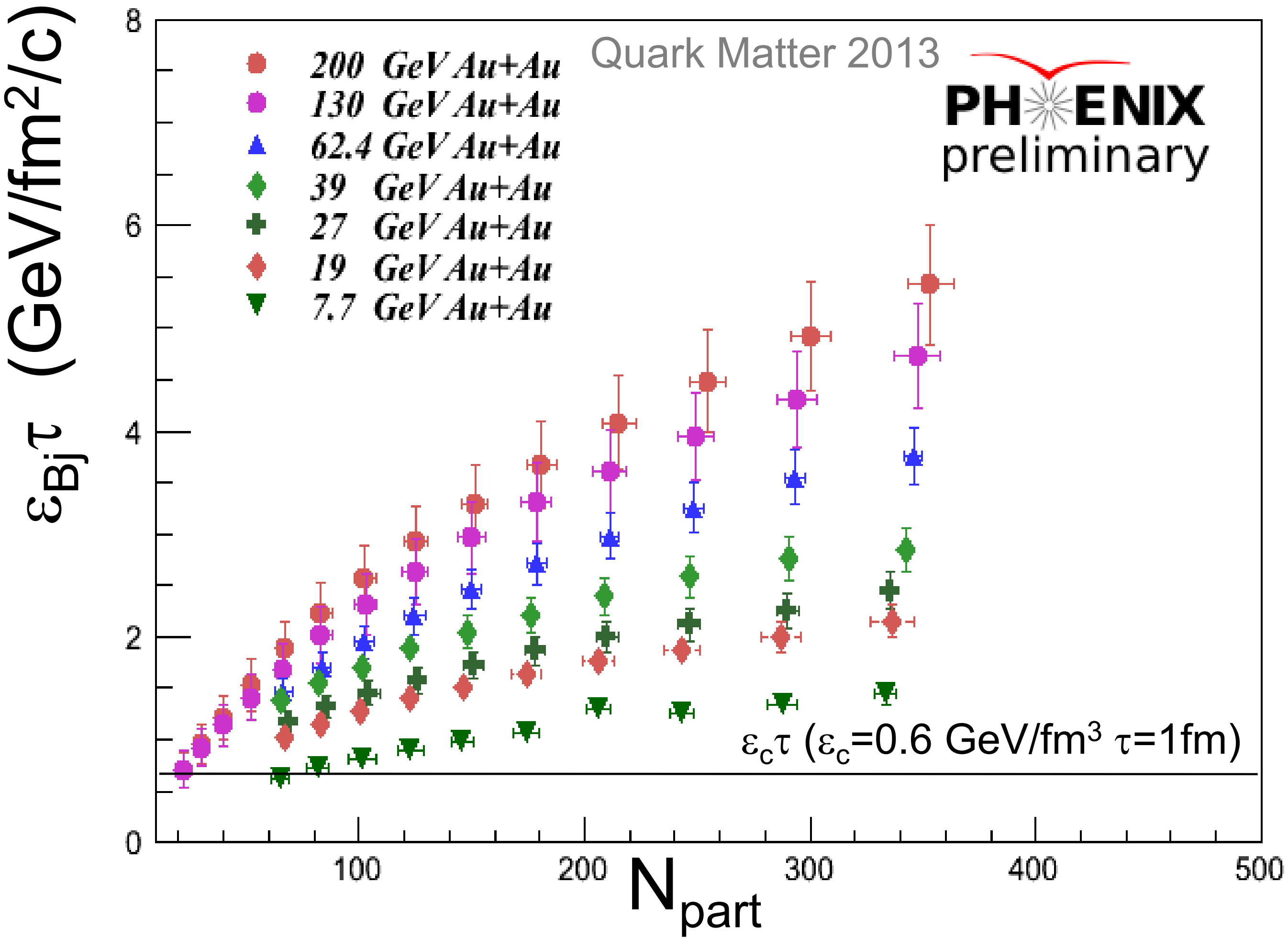


π, K, p used in fits

Blastwave fits seem OK even at lowest collision energies

Expansion gets less violent and kinetic freeze-out occurs "earlier" (or at least higher T)

Generic features of A-A collisions - III

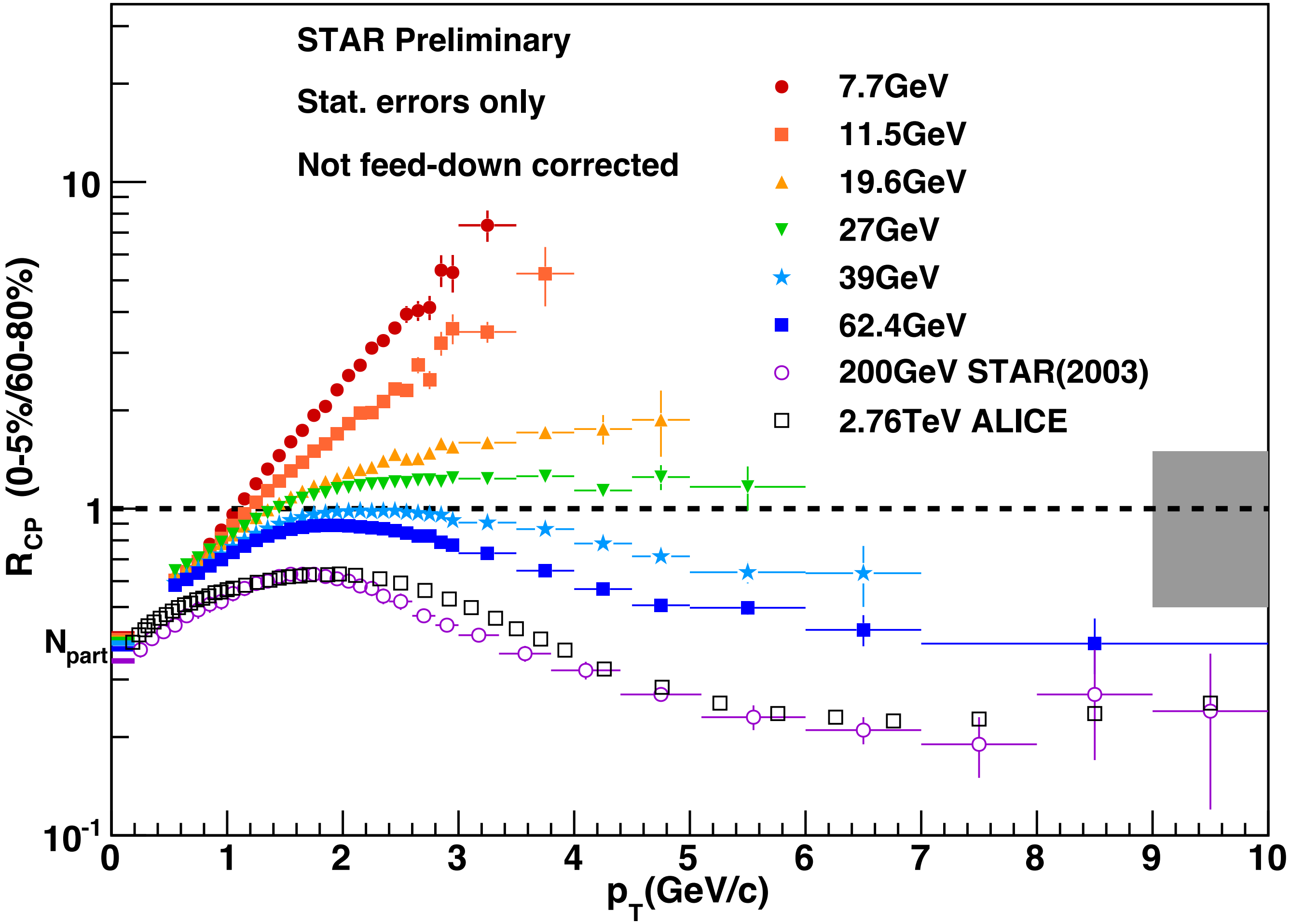


Lattice:
ε_c ~ 0.6 GeV/fm^3

Above critical density for all collision energies and centralities

QGP at all energies?

Charged hadron R_{CP}



Lower energies strongly enhanced - Cronin effect?

Drops below unity for $\sqrt{s_{NN}} \geq 39$ GeV

Need to disentangle Cronin and jet quenching effects

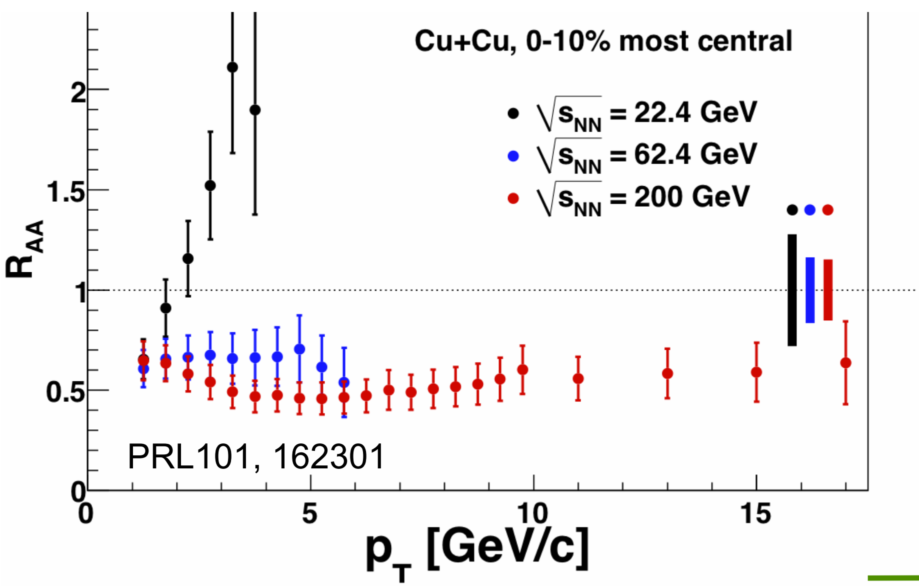
Au-Au vs Cu-Cu

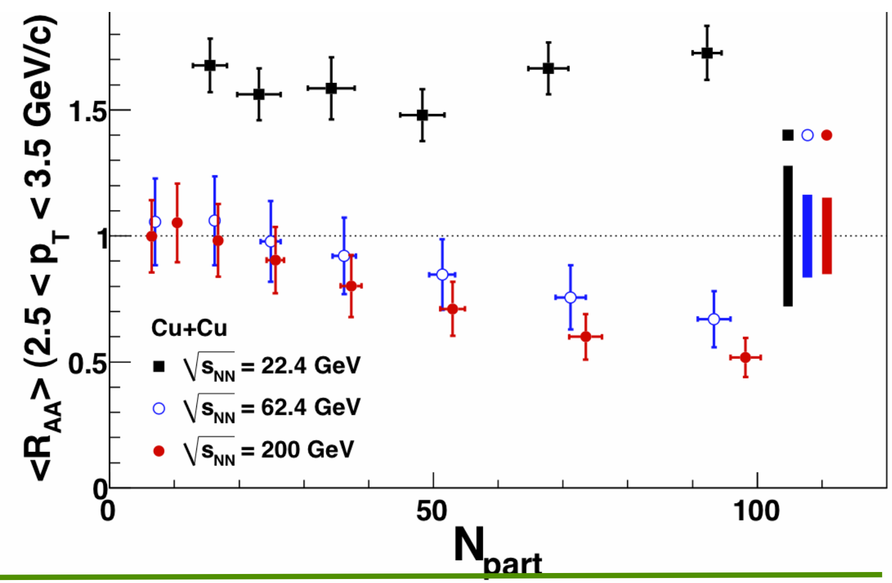
Mitchel CPOD

π^0

Cu-Cu

$R_{AA}^{22.4} > R_{AA}^{62} \sim R_{AA}^{200}$





Au-Au vs Cu-Cu

Mitchel CPOD

π^0

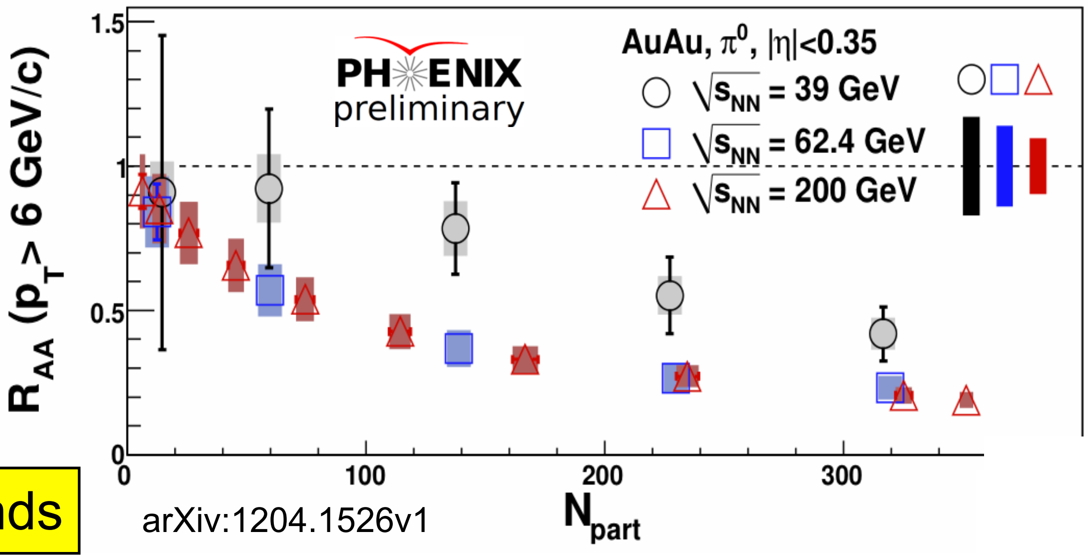
Au-Au

$R_{AA}^{39} > R_{AA}^{62} \sim R_{AA}^{200}$

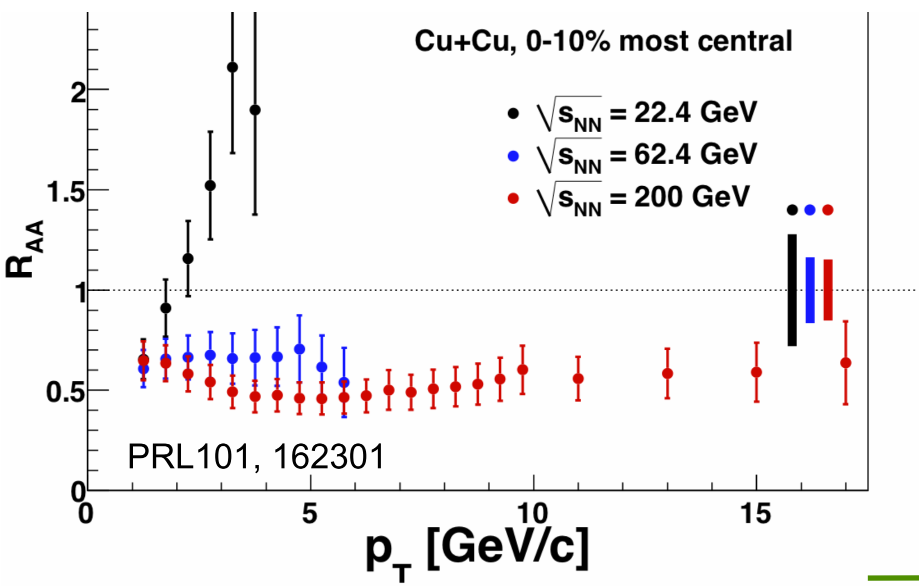
Cu-Cu

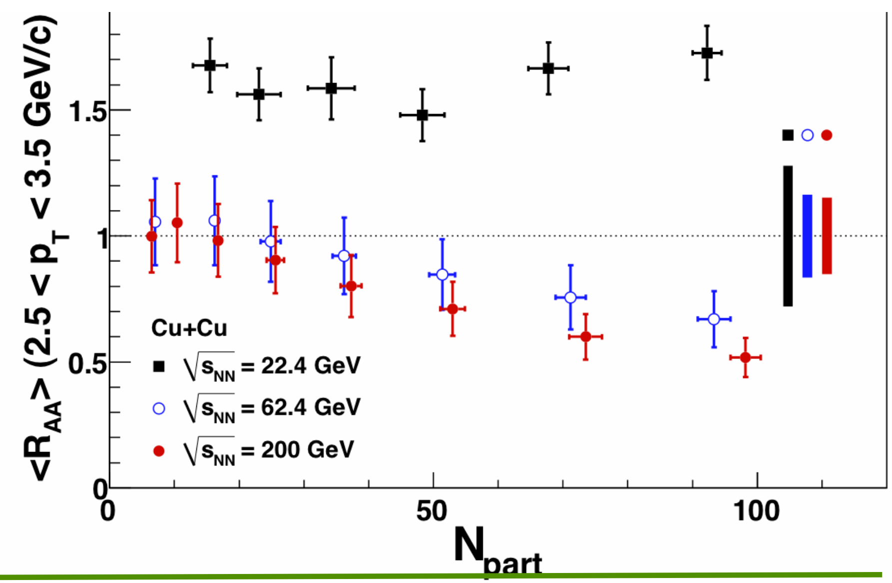
$R_{AA}^{22.4} > R_{AA}^{62} \sim R_{AA}^{200}$

Cu-Cu & Au-Au show similar trends



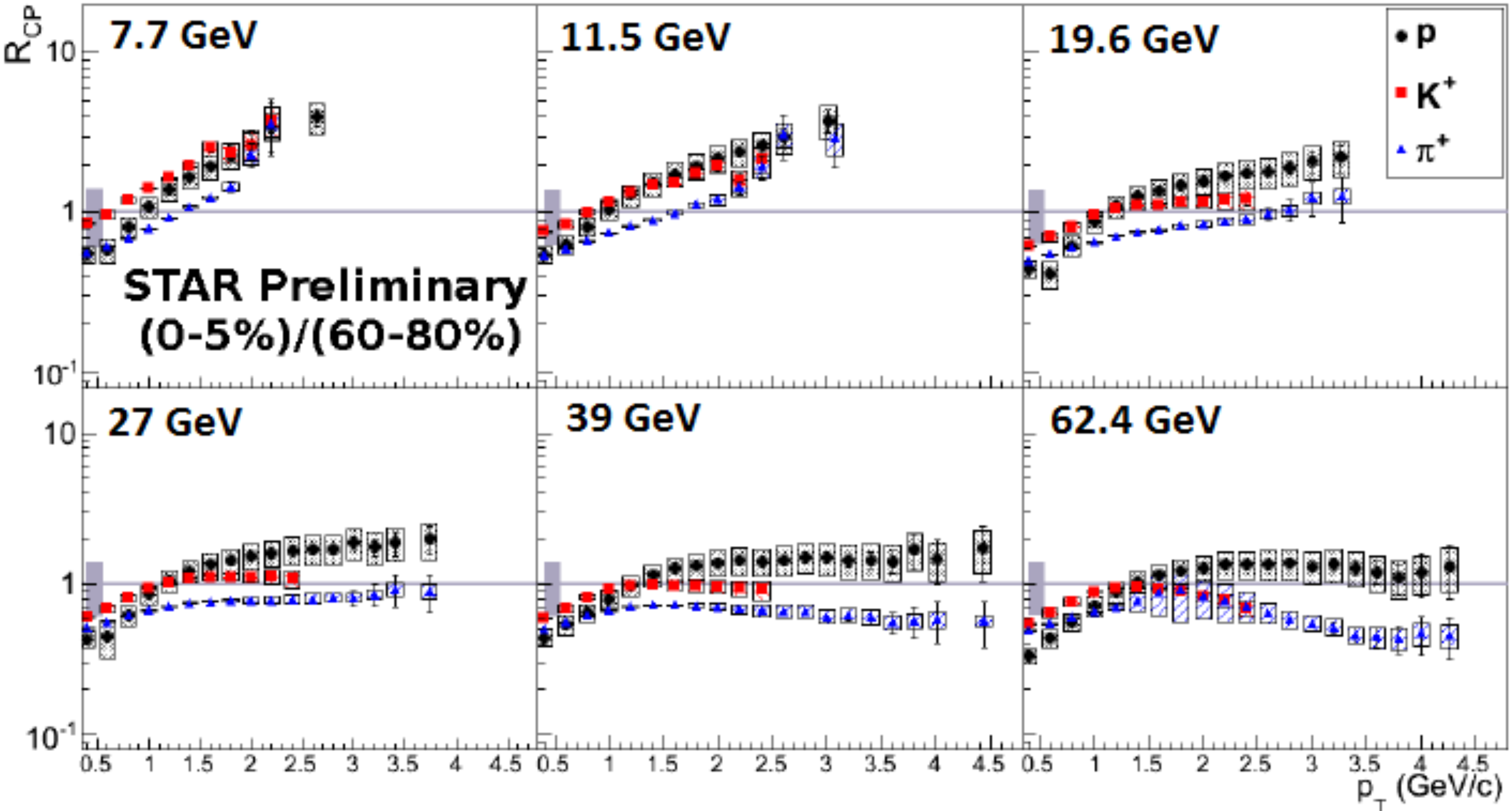
arXiv:1204.1526v1





PID R_{CP}

Horvat CPOD



Species dependent effect seen as in original Cronin data

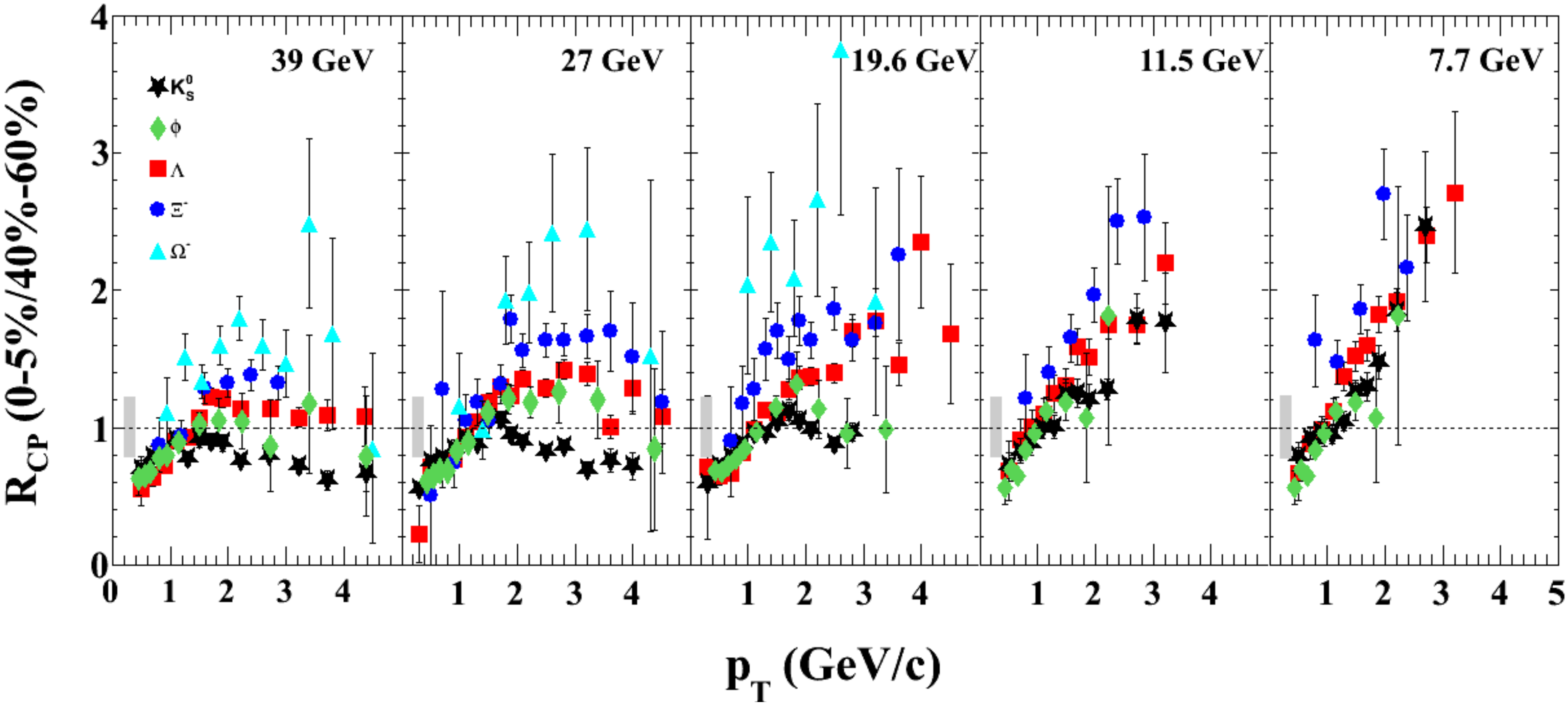
$R_{cp}^{p} > R_{cp}^{K} > R_{cp}^{\pi}$

Particle ratios changing as function of $\sqrt{s_{NN}}$

Similar features seen for anti-particles

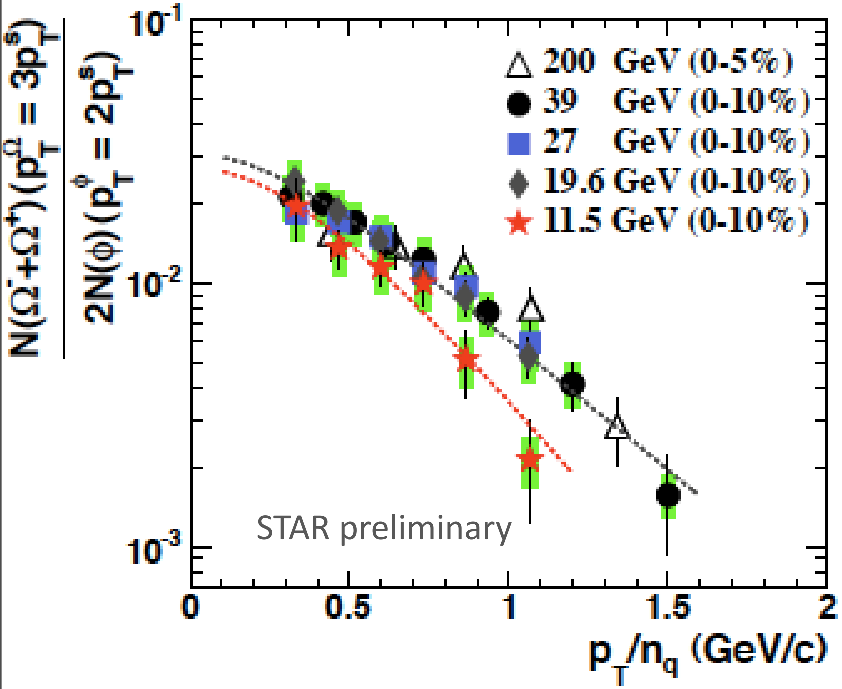
Strangeness R_{CP}

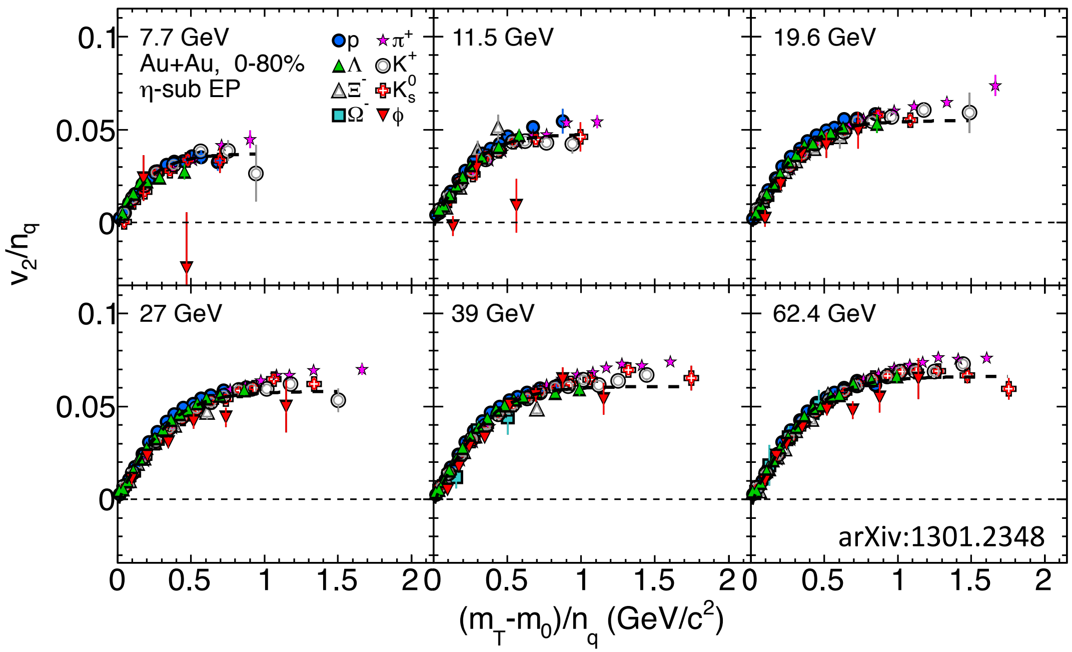
Nasim CPOD



Cronin effect seems to be a mass effect - although errors large

Parton recombination ending





Between 19.6 and 11 GeV:

Derived s quark p_T distribution changes

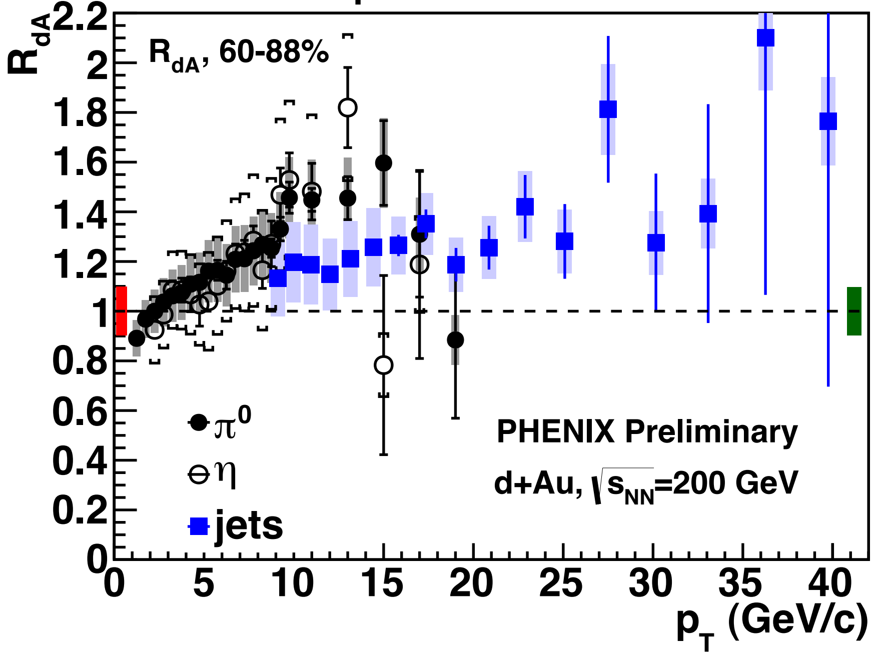
Change in dominant particle production mechanisms?

ϕ v_2 no longer follows meson distribution
- low ϕ v_2 could imply hadronic dominance

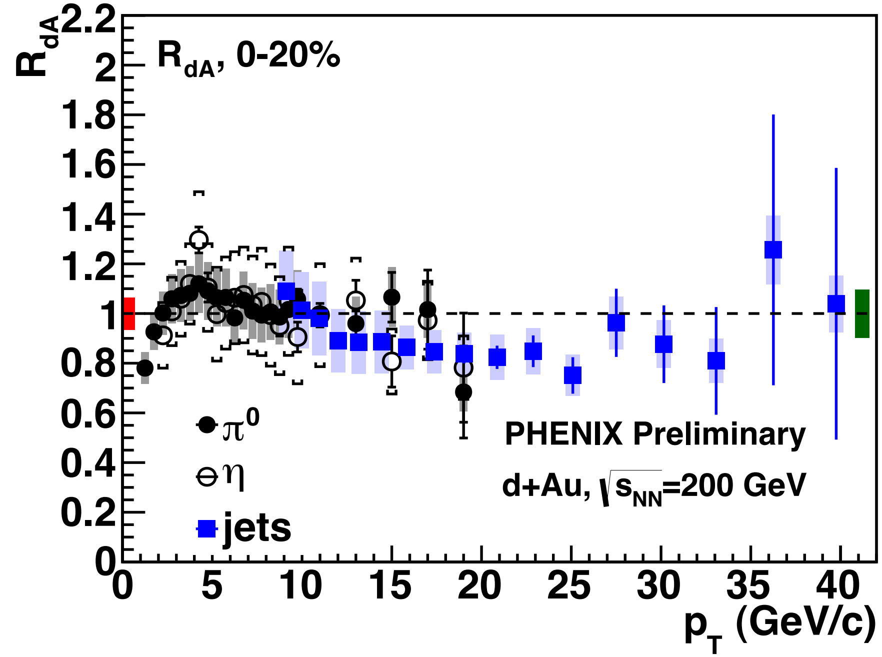
(Better statistics would be nice)

R_{AA} vs R_{CP}

Peripheral



Central



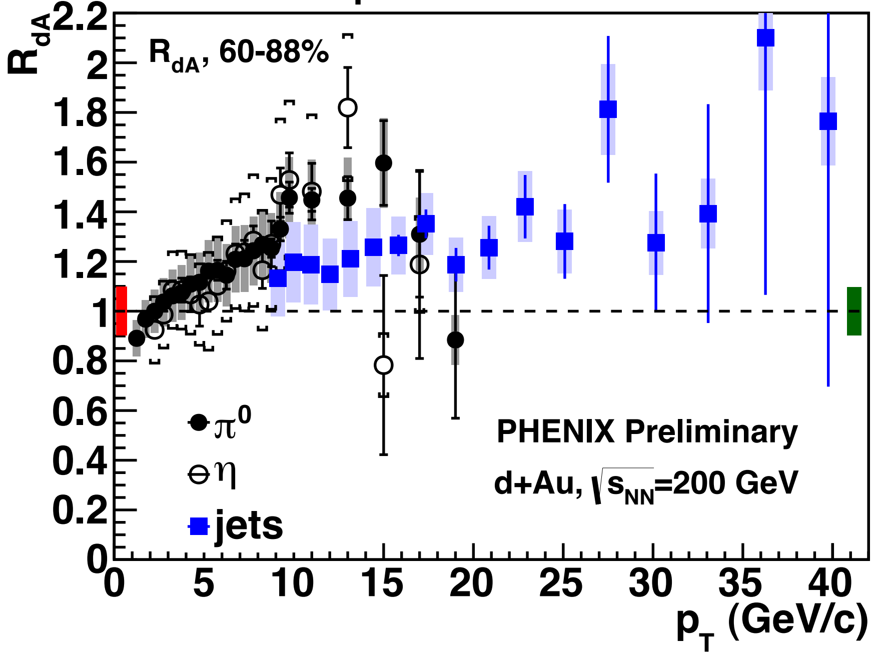
Centrality dependence to the Cronin Effect?

Au-Au 200

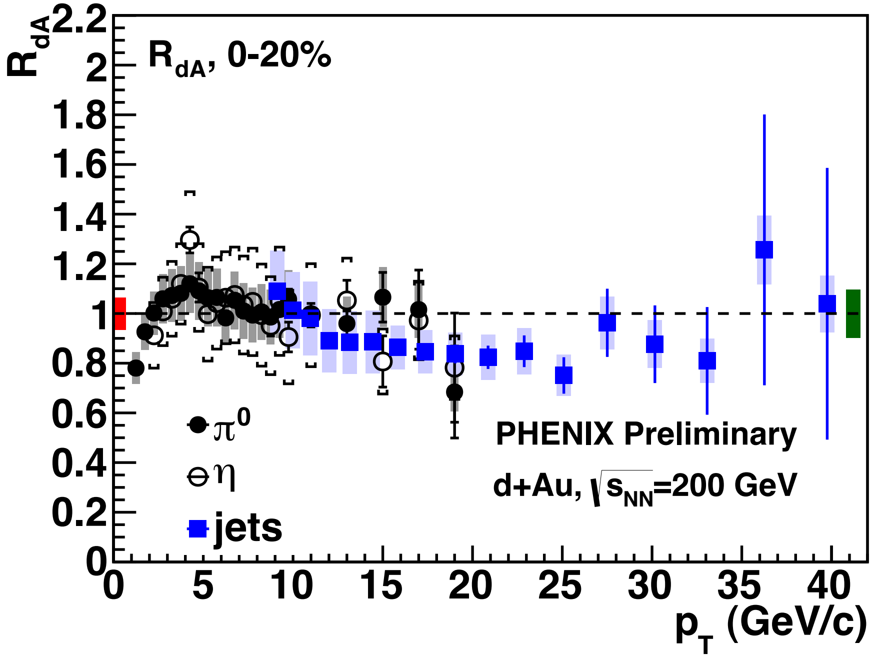
d-Au: enhancement larger in peripheral collisions
- were expected to be more “p-p” like

R_{AA} vs R_{CP}

Peripheral



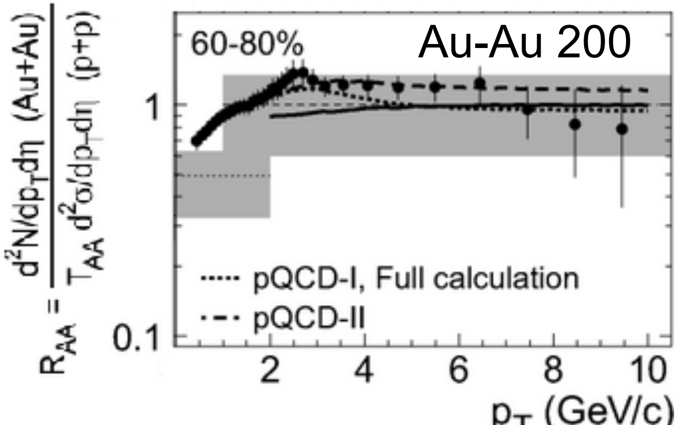
Central



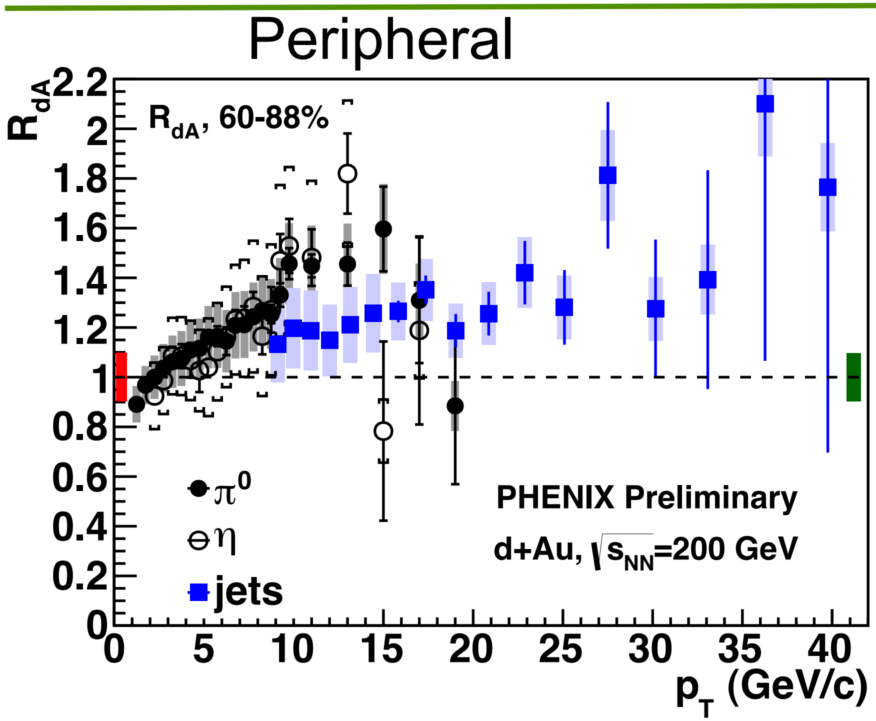
Centrality dependence to the Cronin Effect?

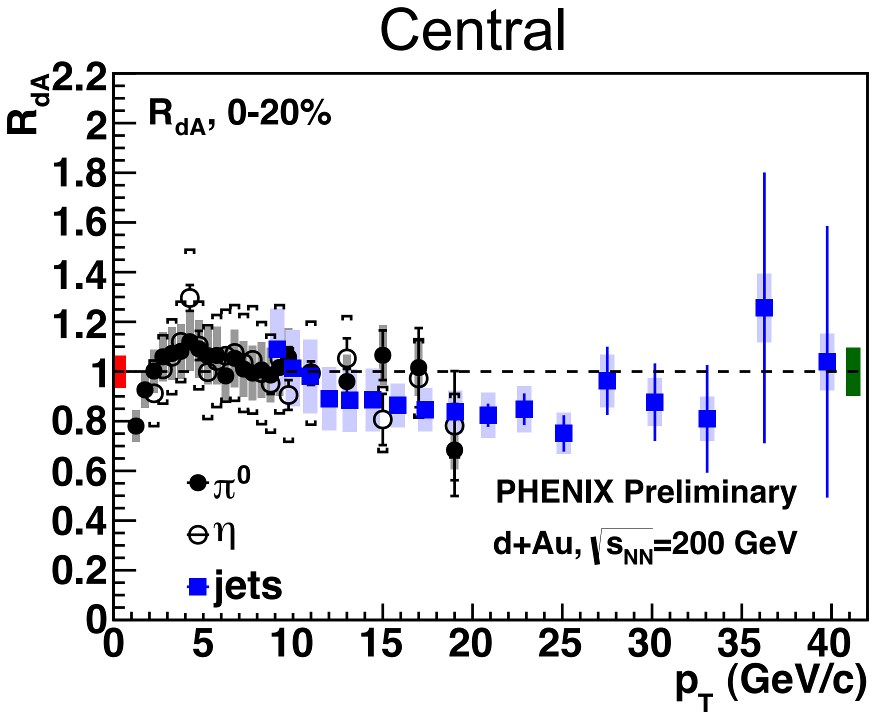
d-Au: enhancement larger in peripheral collisions

- were expected to be more "p-p" like



R_{AA} vs R_{CP}

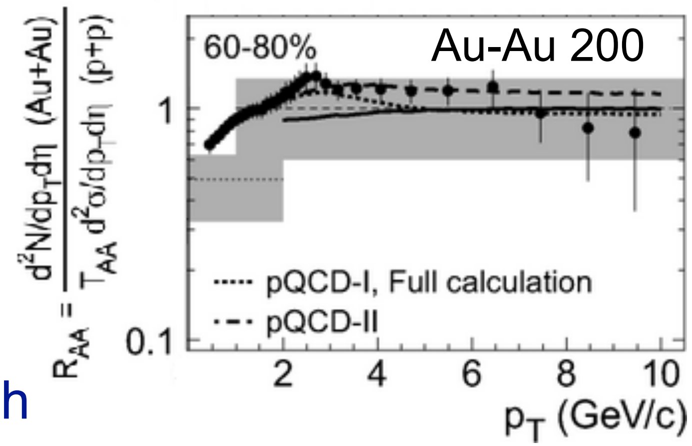




Centrality dependence to the Cronin Effect?

d-Au: enhancement larger in peripheral collisions

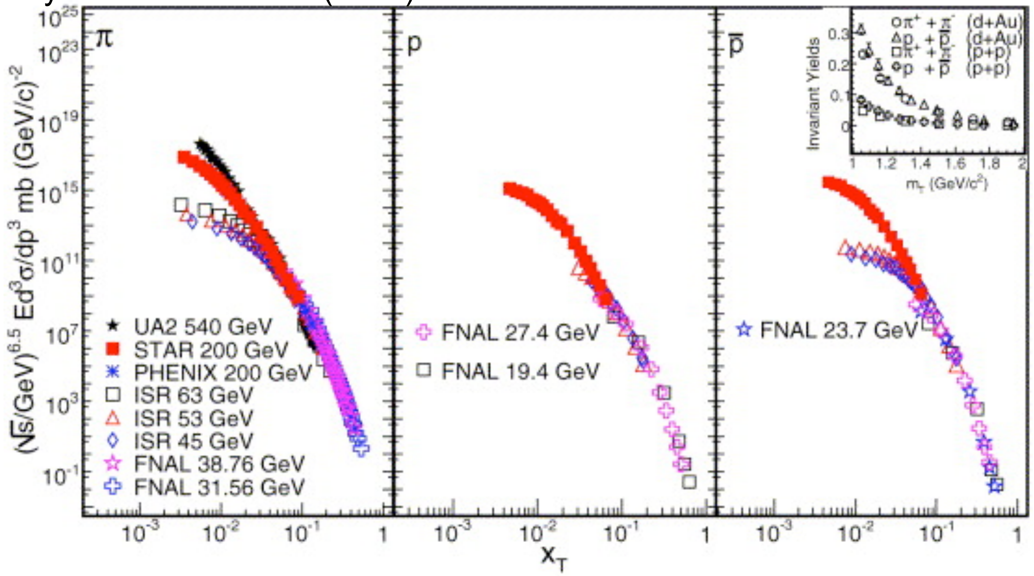
- were expected to be more "p-p" like



R_{CP} cancels some of the Cronin - maybe too much

Is x_T better variable than p_T?

Physics Letters B 637 (2006) 161–169



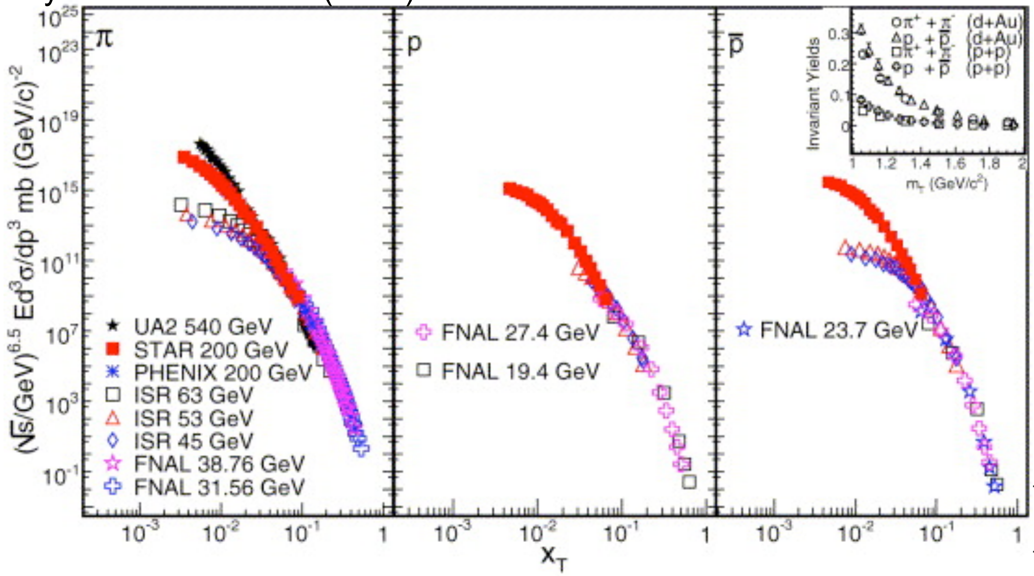
$$x_T = \frac{2p_T}{\sqrt{s}}$$

p-p spectra converge at large x_T over large range in $\sqrt{s_{NN}}$ when yield scaled by $(\sqrt{s}/GeV)^{6.5\pm0.8}$

Does this scaling persist in A-A collisions?

Is x_T better variable than p_T?

Physics Letters B 637 (2006) 161–169

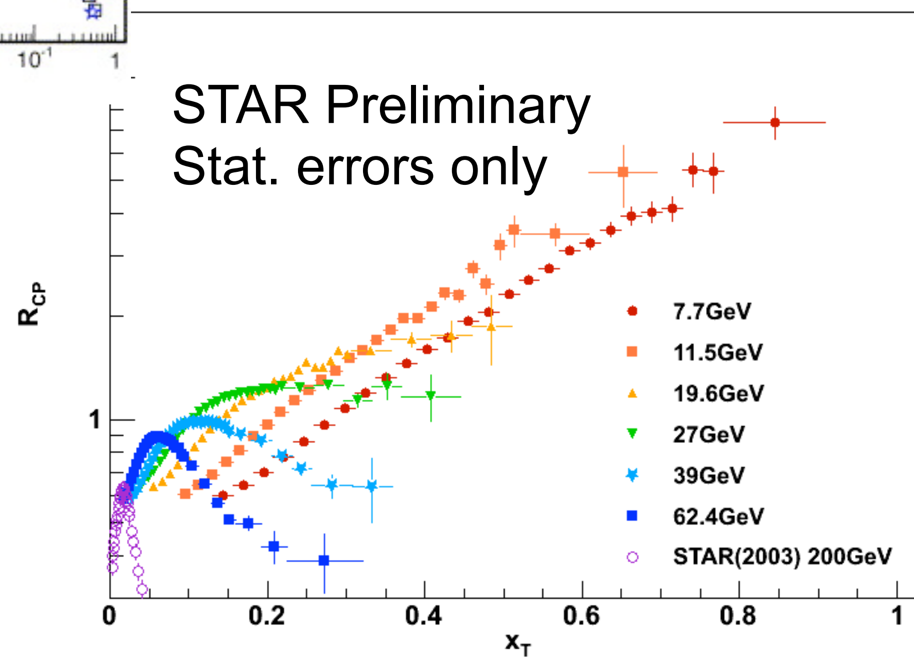


p-p spectra converge at large x_T over large range in $\sqrt{s_{NN}}$ when yield scaled by $(\sqrt{s}/GeV)^{6.5\pm0.8}$

Does this scaling persist in A-A collisions?

$$x_T = \frac{2p_T}{\sqrt{s}}$$

R_{CP}: $\sqrt{s_{NN}}$ dependence remains



x_T not the appropriate scaling and/or centrality dependence to exponent (6.5±0.8)

Horvat CPOD

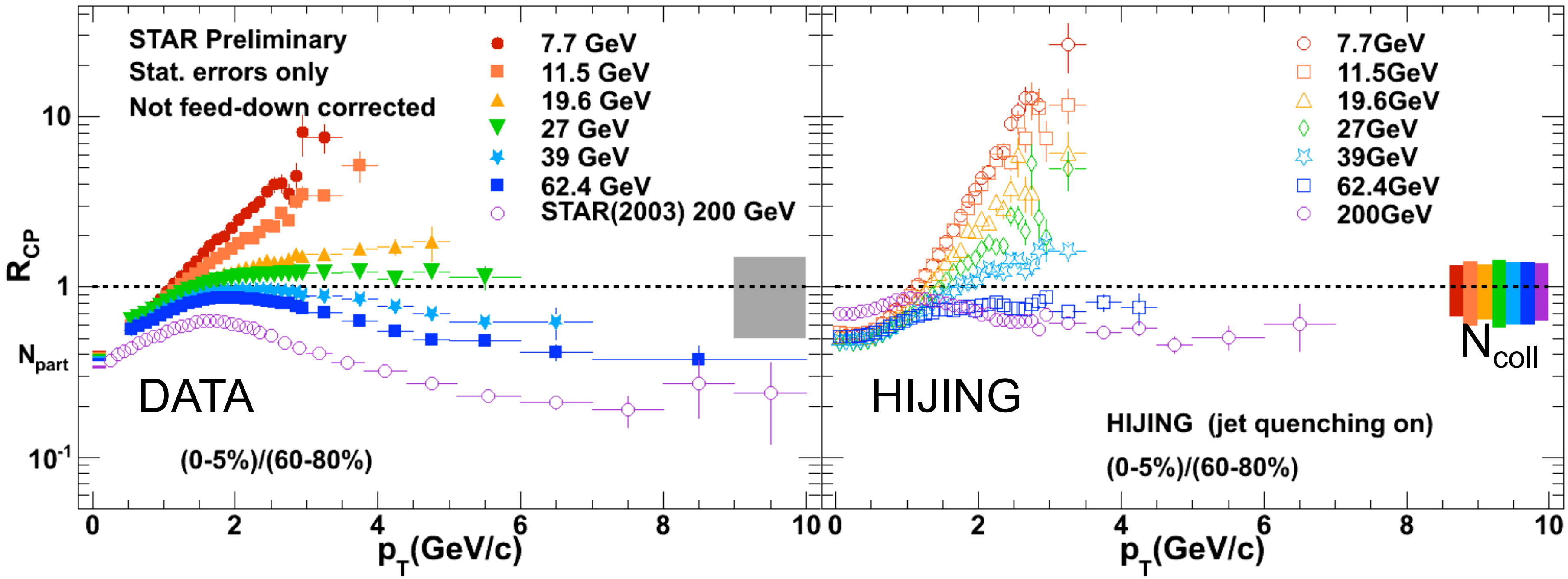
Can we extract Cronin from models

- HIJING 1.383
  - jet quenching on or off
  - modeled as -dE/dx within the medium
  - default Lund splitting parameters a=0.5,b=0.9

- AMPT v1.21/v2.21(uses HIJING 1.383)
  - string melting (SM) off uses Lund string fragmentation for hadronization (v1.21)
  - SM on uses quark coalescence for hadronization (v2.21)
  - default Lund splitting parameters a=2.2, b=0.5

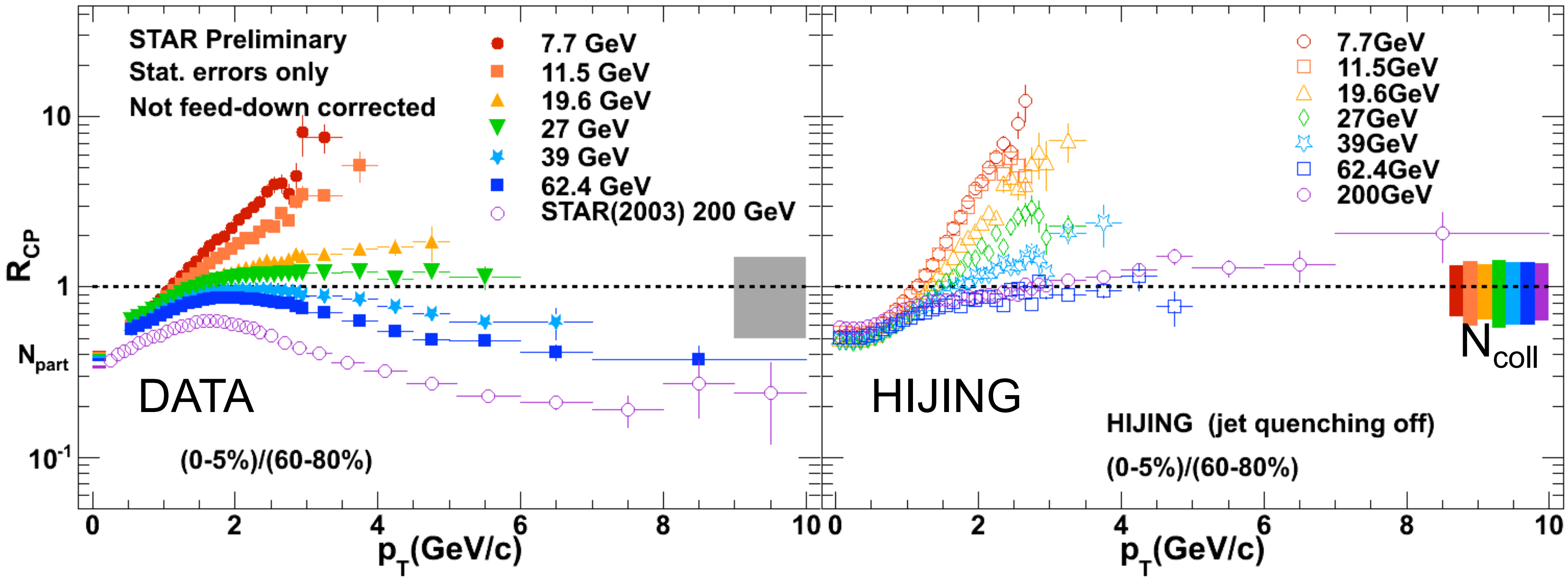
Lund fragmentation formula: $f(z) \propto \frac{(1-z)^a}{z} e^{-bm_\perp^2/z}$

HIJING quenching on



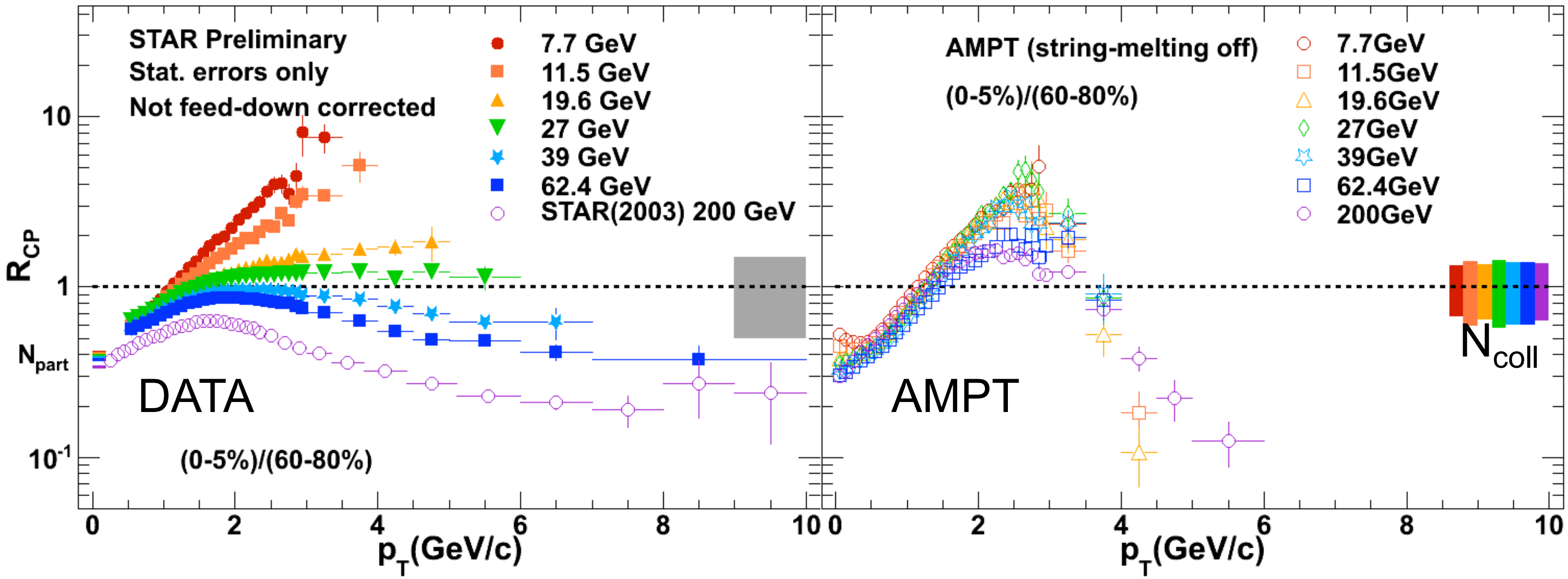
- Similar behavior to data
- 200 GeV has odd low p_T behavior
- Generally overestimates R_{CP}

HIJING quenching off



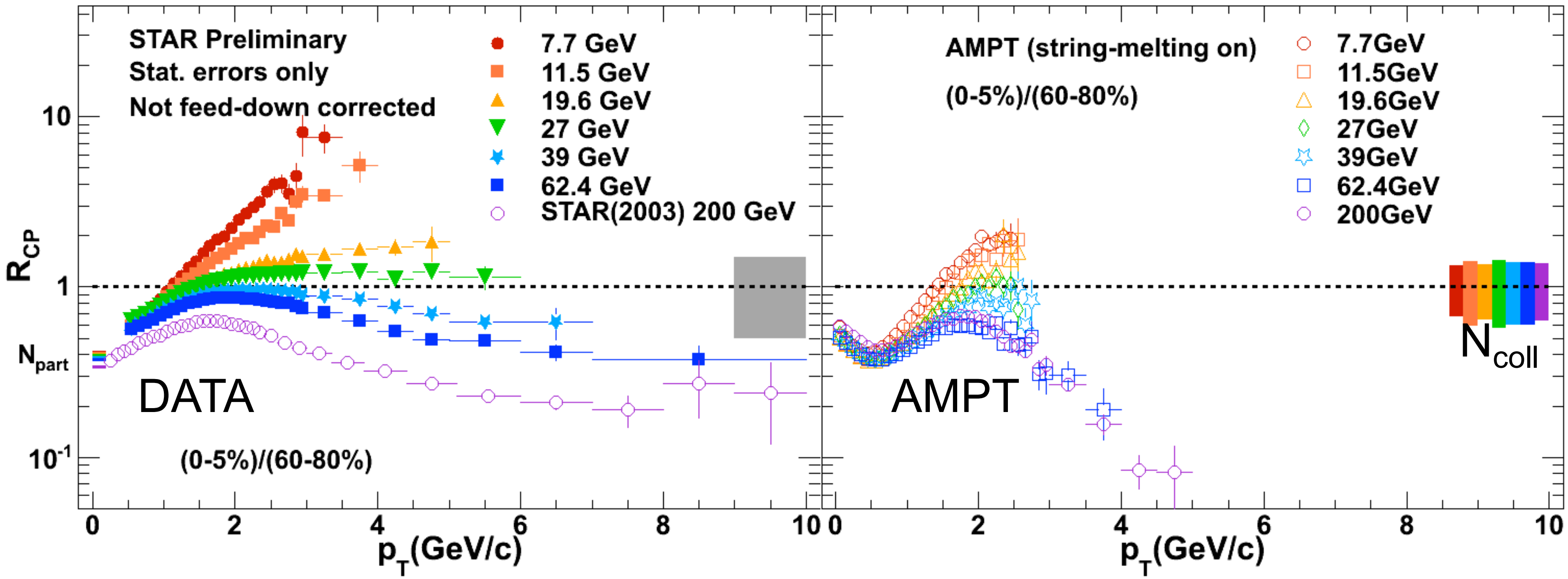
- 200 GeV better behaved at low p_T
- 7.7 GeV barely changed from quenching on

AMPT SM off



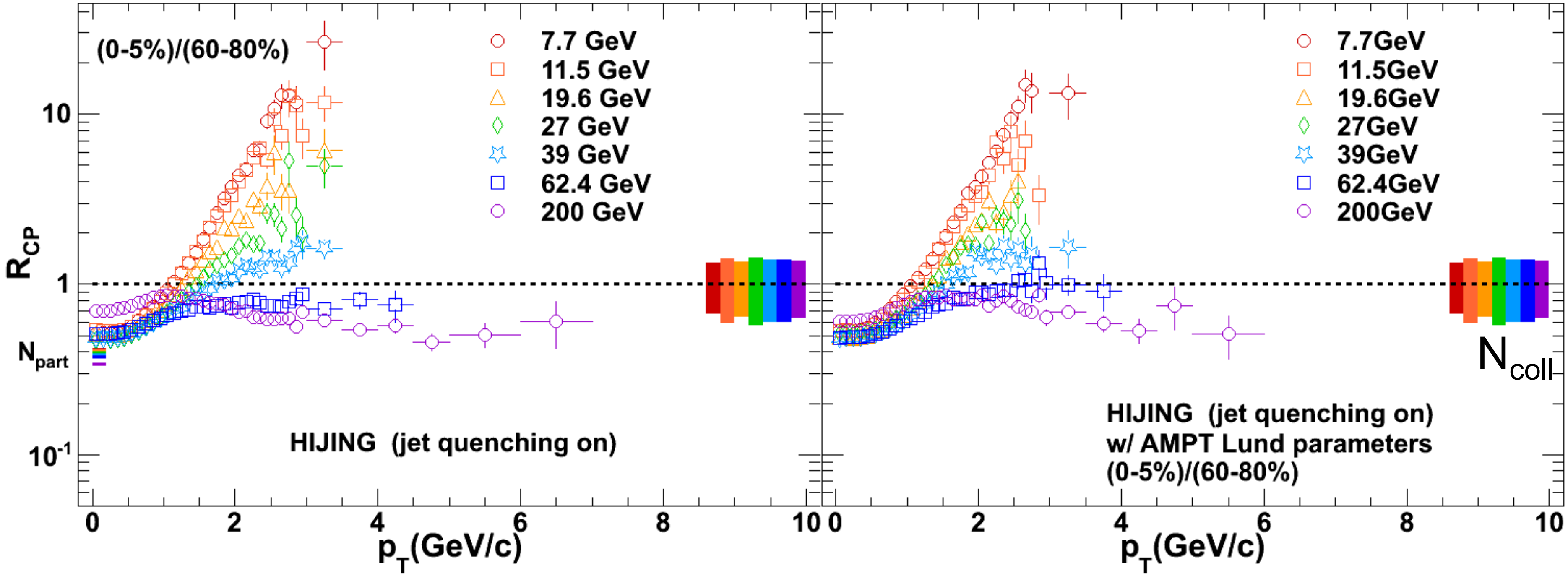
- Minimal beam energy dependence
- Sharp turn over near 2.5 GeV/c

AMPT SM on



- recovers beam energy dependence
- limited p_T reach
  - same number of events for SM on/off

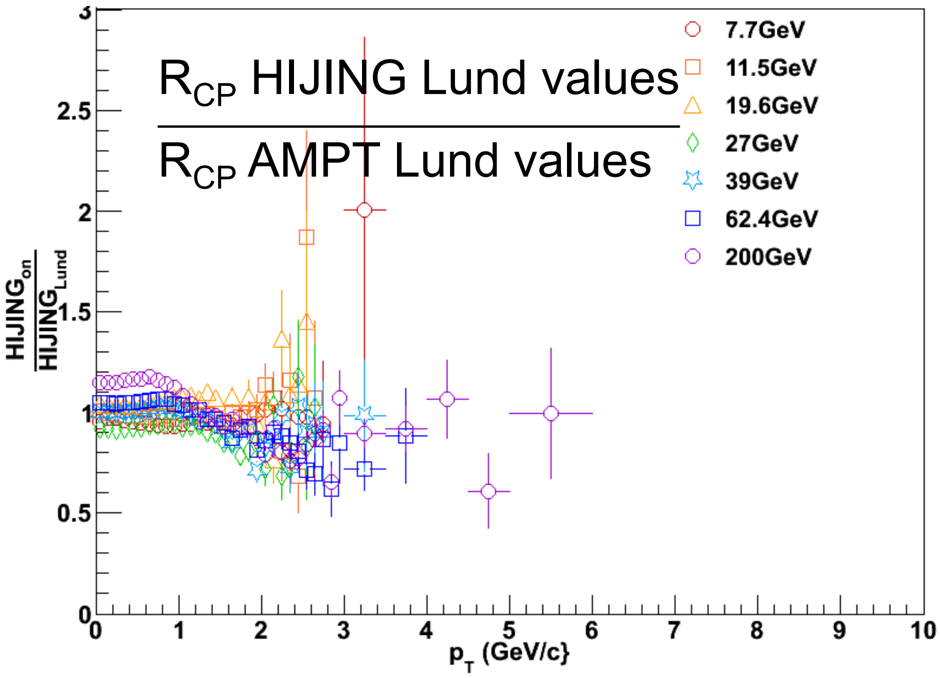
HIJING default/AMPT settings



HIJING with default or AMPT's Lund splitting parameters

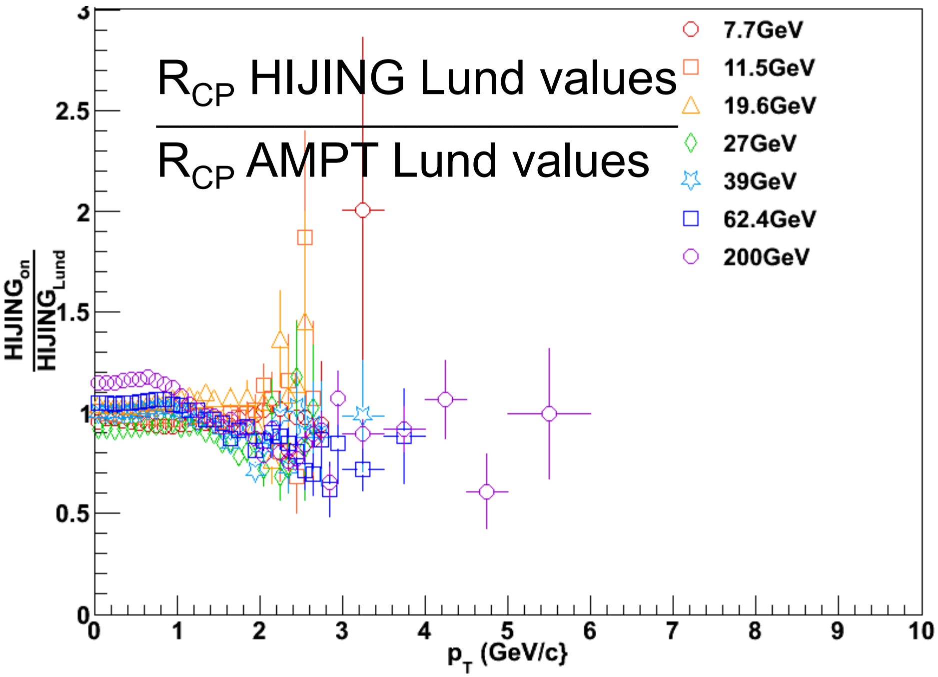
- small effect on R_{CP}

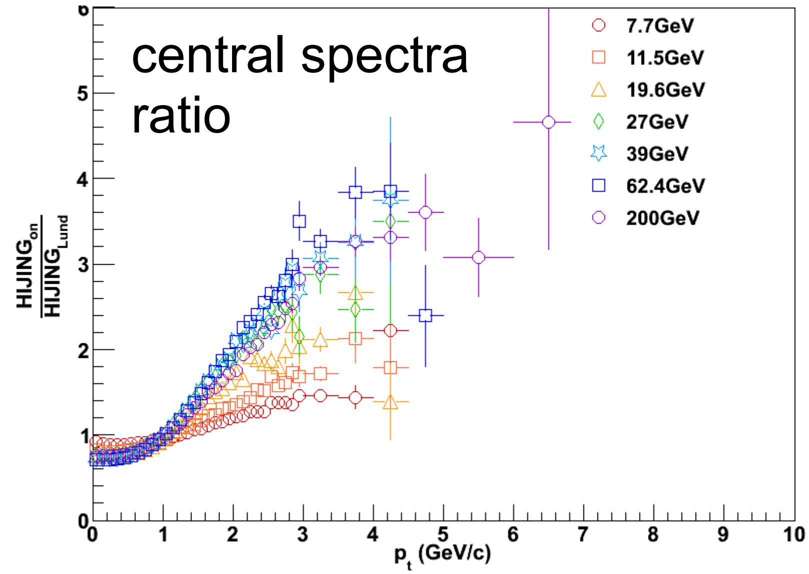
HIJING with differing Lund parameters

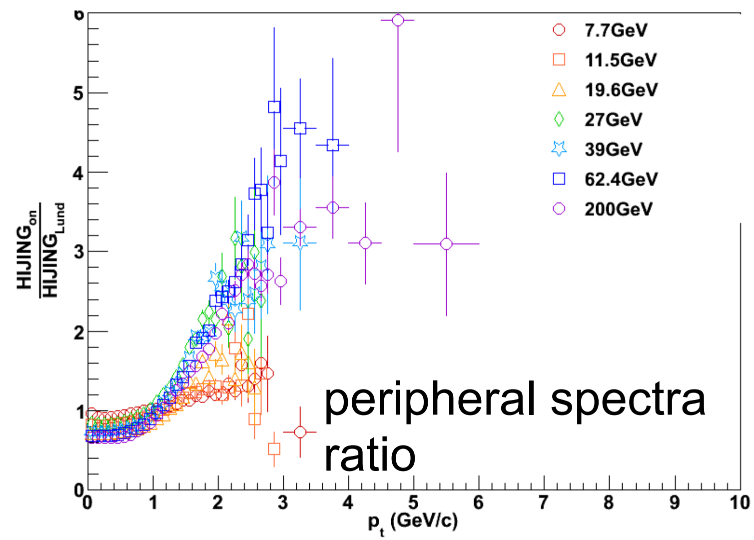


R_{CP} essentially unchanged

HIJING with differing Lund parameters







R_{CP} essentially unchanged

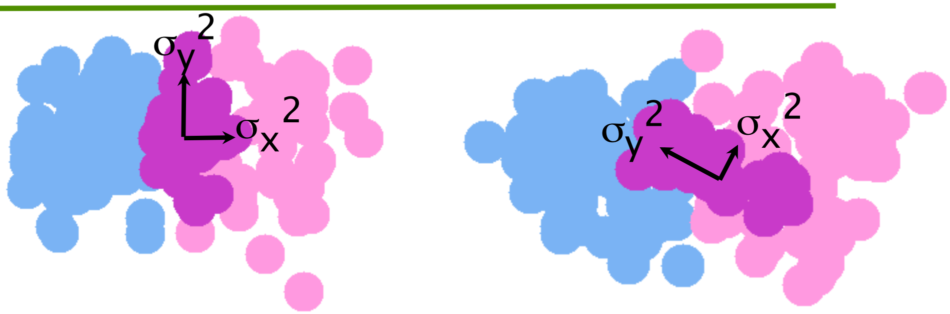
Peripheral and central spectra vary in same manner

Conclusions on quenching

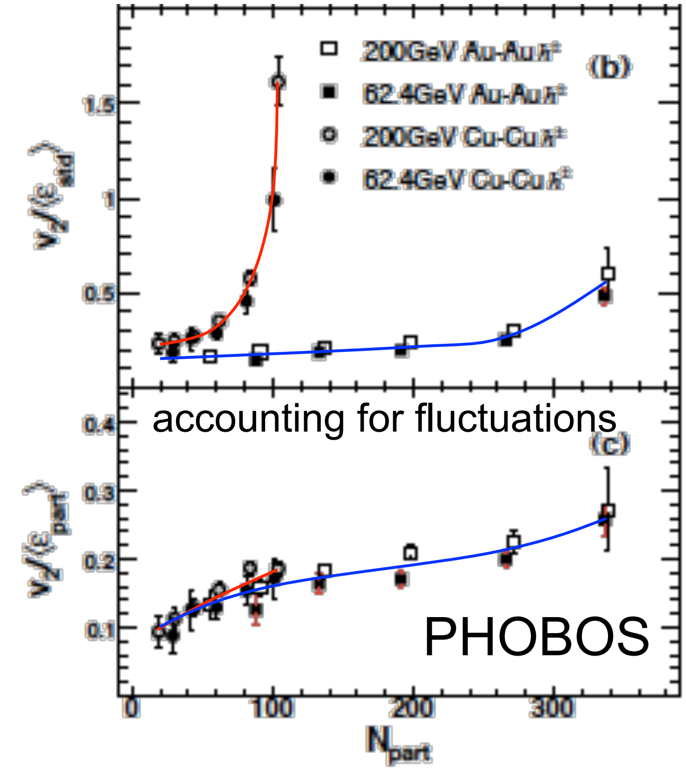
- Results taken at face value suggest QGP down to lowest beam energy
- Disentangling initial from final state close to impossible without control data
- (some) Models get trends OK but none get details
- Need to compare to numerous measurements to gain understanding
- BES data confusing, and more interesting than folks thought

Initial Conditions

Importance of initial conditions



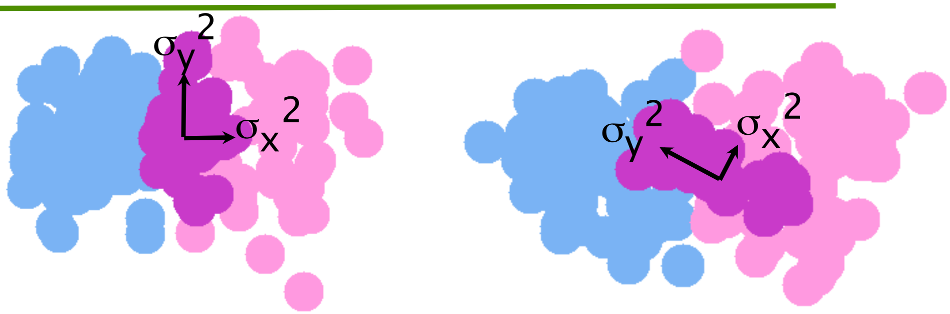
Phys. Rev. Lett. 98, 242302 (2007)



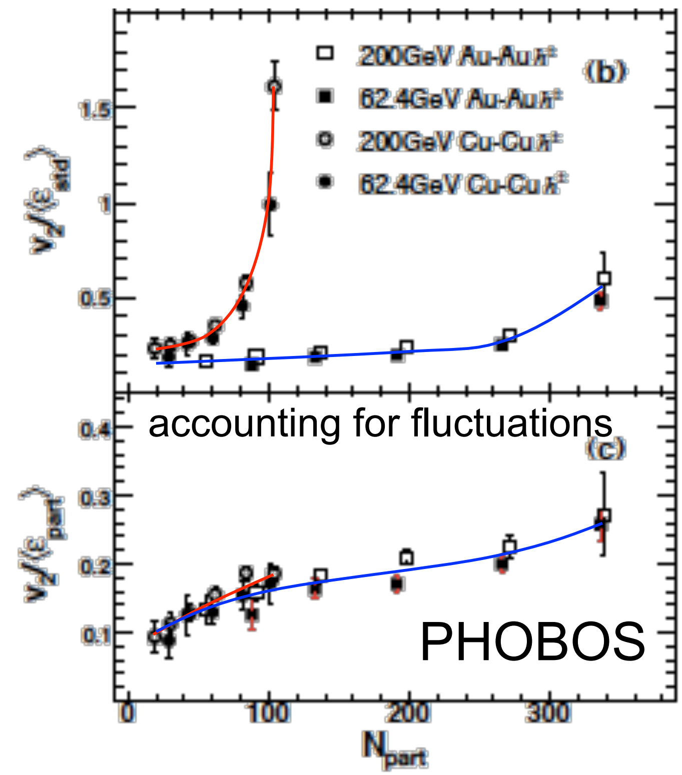
PHOBOS - Cu-Cu importance of principle axis

Alver and Roland - v_3 exists and plays key role

Importance of initial conditions



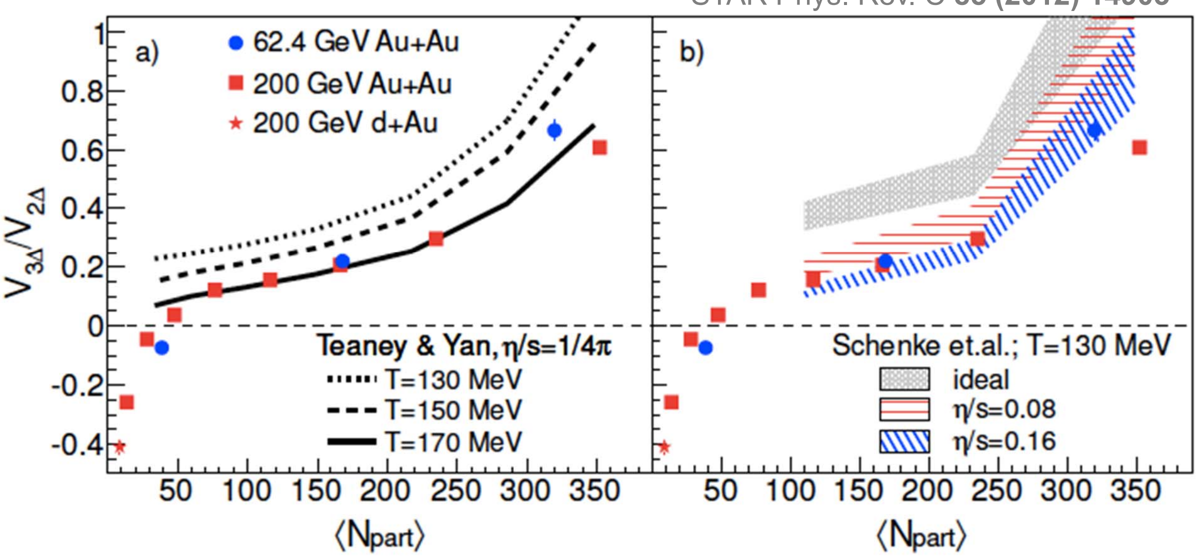
Phys. Rev. Lett. 98, 242302 (2007)



PHOBOS - Cu-Cu importance of principle axis

Alver and Roland - v_3 exists and plays key role

STAR Phys. Rev. C **85 (2012) 14903**

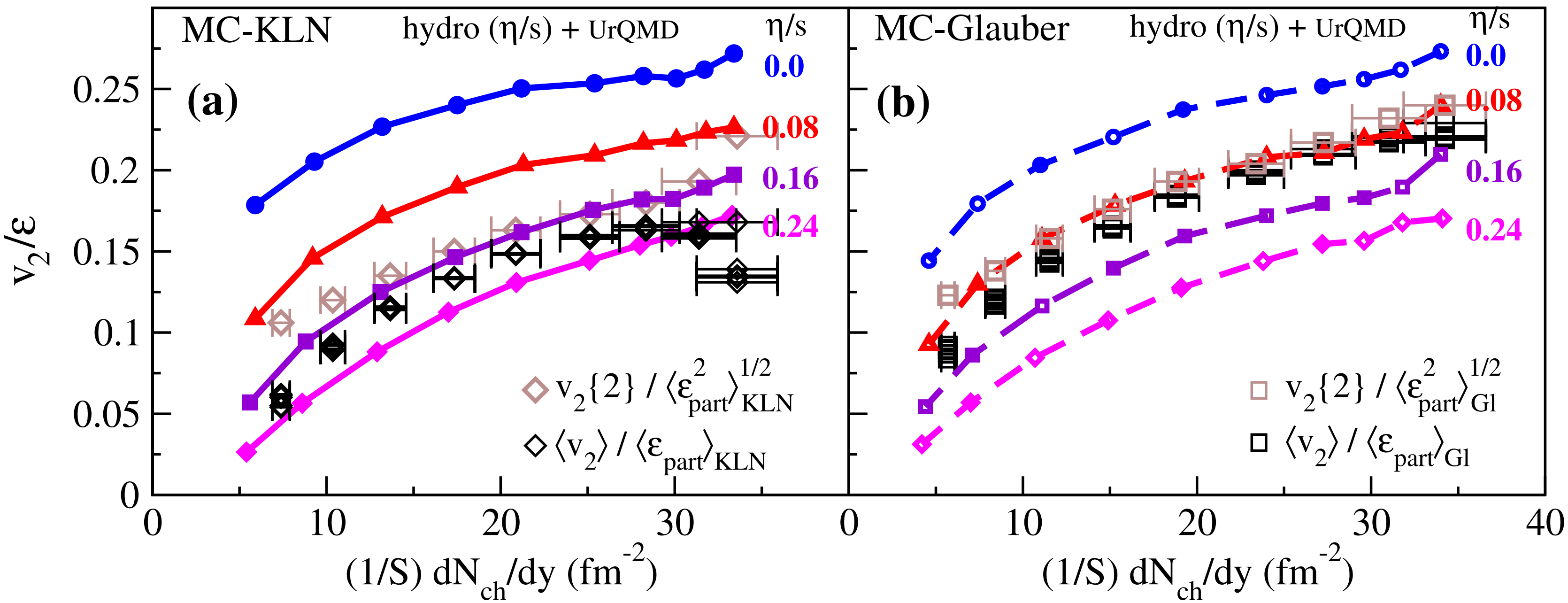


Viscosity or T can be tuned to match $V_{3\Delta}/V_{2\Delta}$

Need variety of data to pin down initial conditions

Importance of initial conditions - II

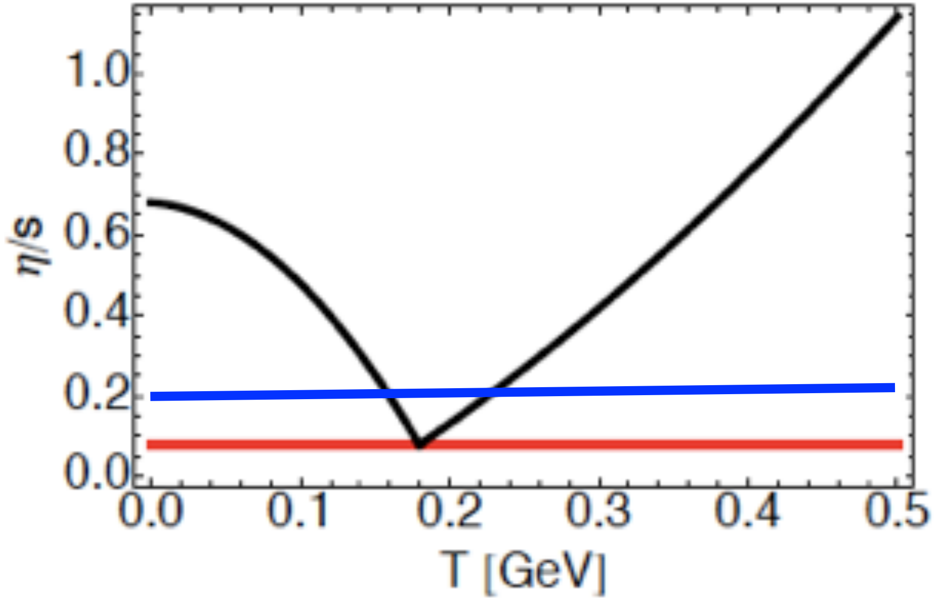
Song et al. PRL 106 192301 (2011)



$$\frac{\eta}{s} = 0.08 \rightarrow 0.2$$

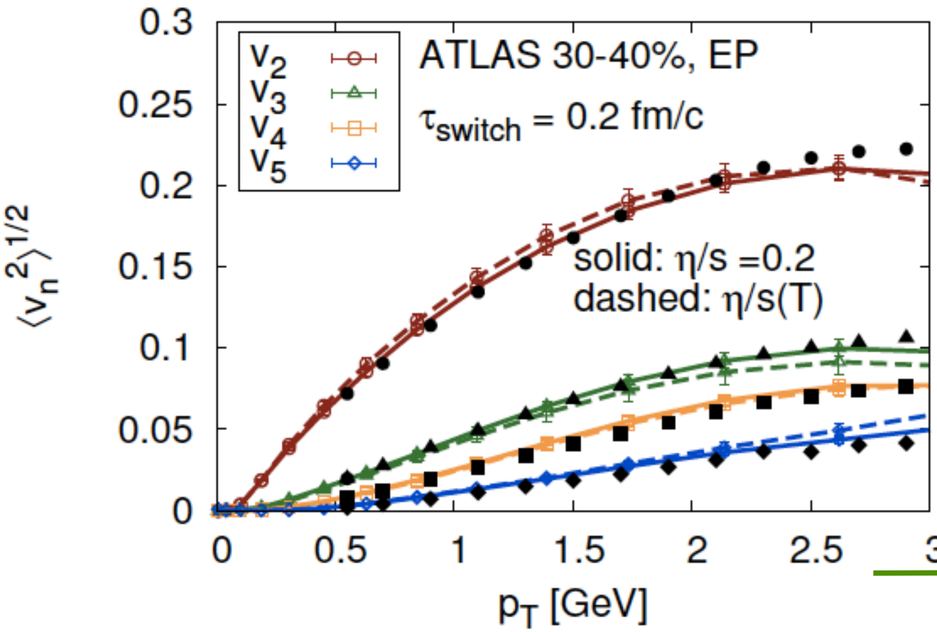
Details of initial configuration are large source of uncertainty

Importance of Initial conditions - III



Gale, Jeon, Schenke, Tribedy, Venugopalan

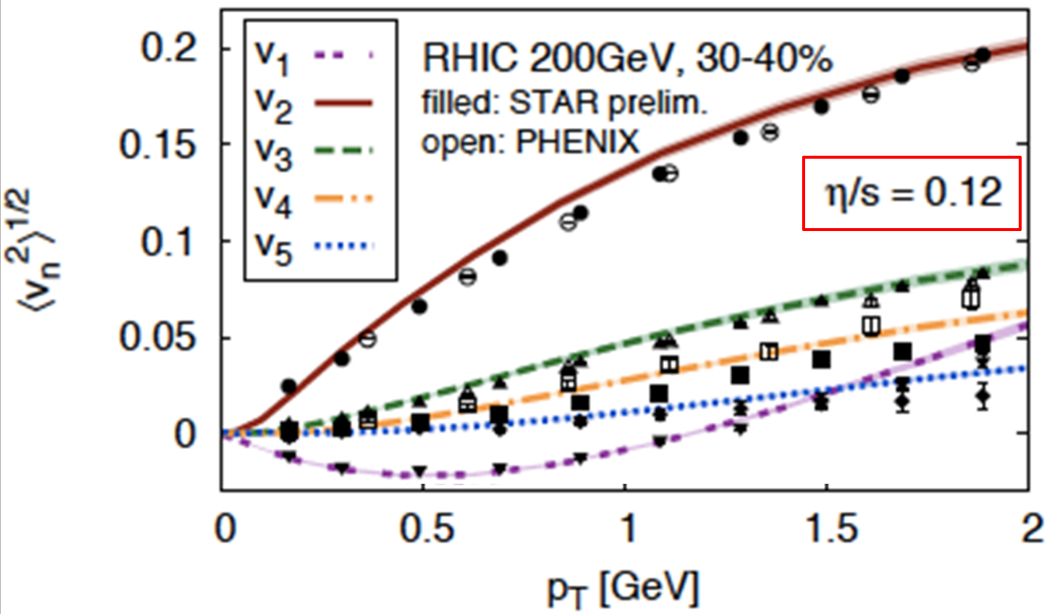
Different functional forms for η/s(T) can result in similar mean η/s values



Can't distinguish with models between constant η/s or temperature dependent η/s with minimum at T_c with only one collision energy

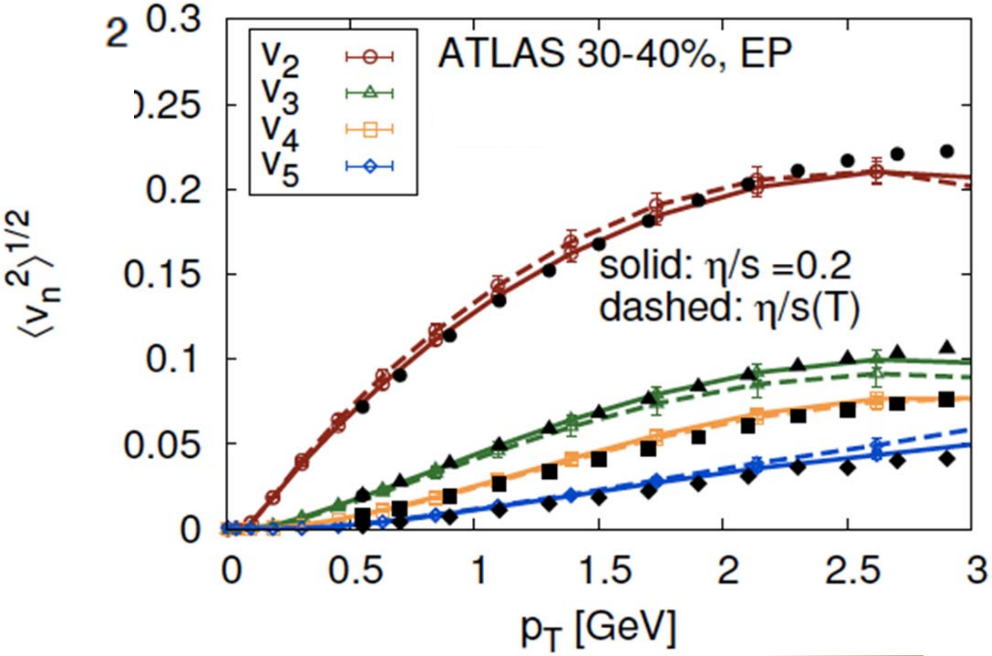
Variety of collision energies needed to disentangle

η/s as a function of collision energy

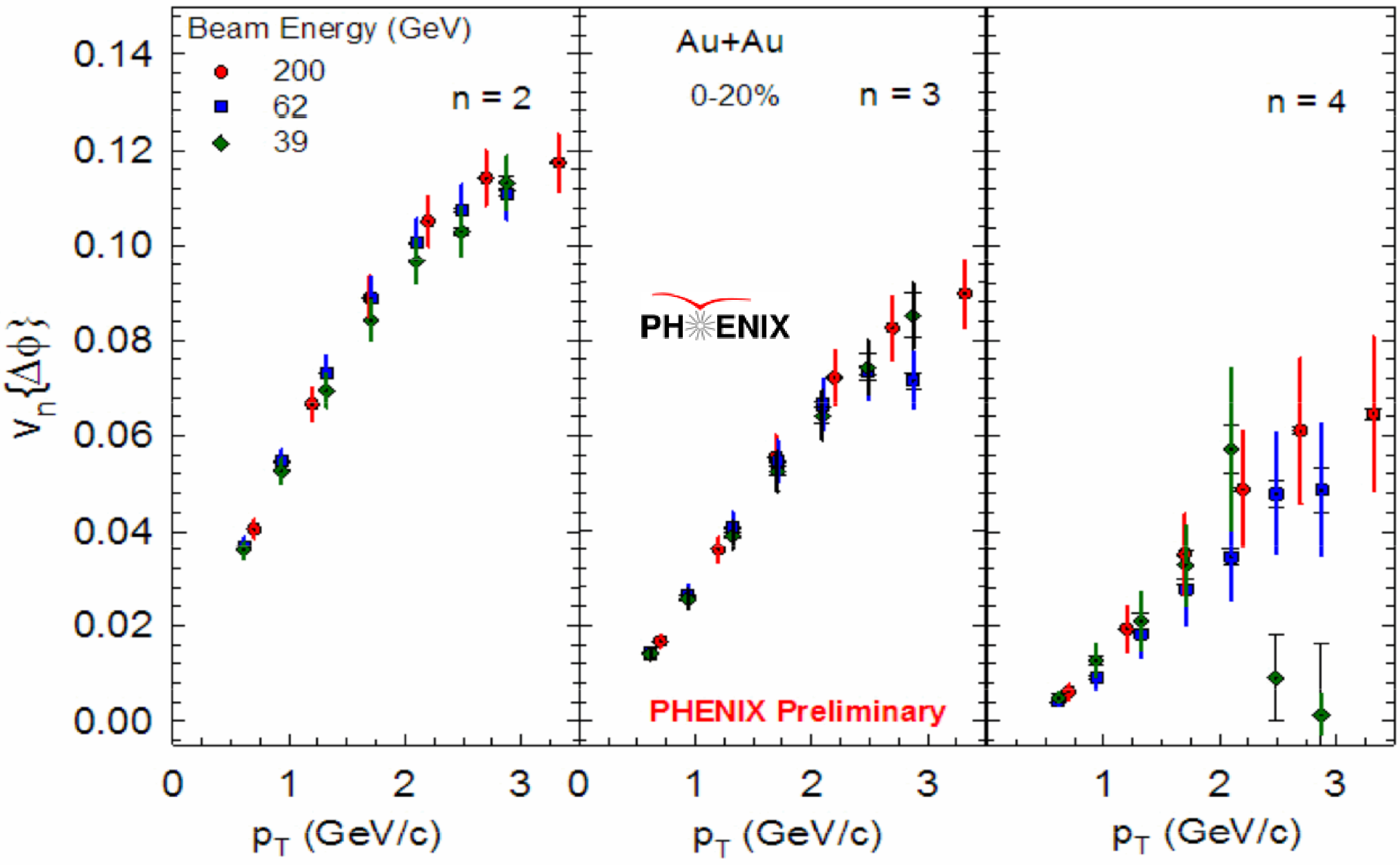


Mean η/s 40% smaller at top RHIC energies than at the LHC

Does this keep dropping with beam energy?



V_n at top beam energies

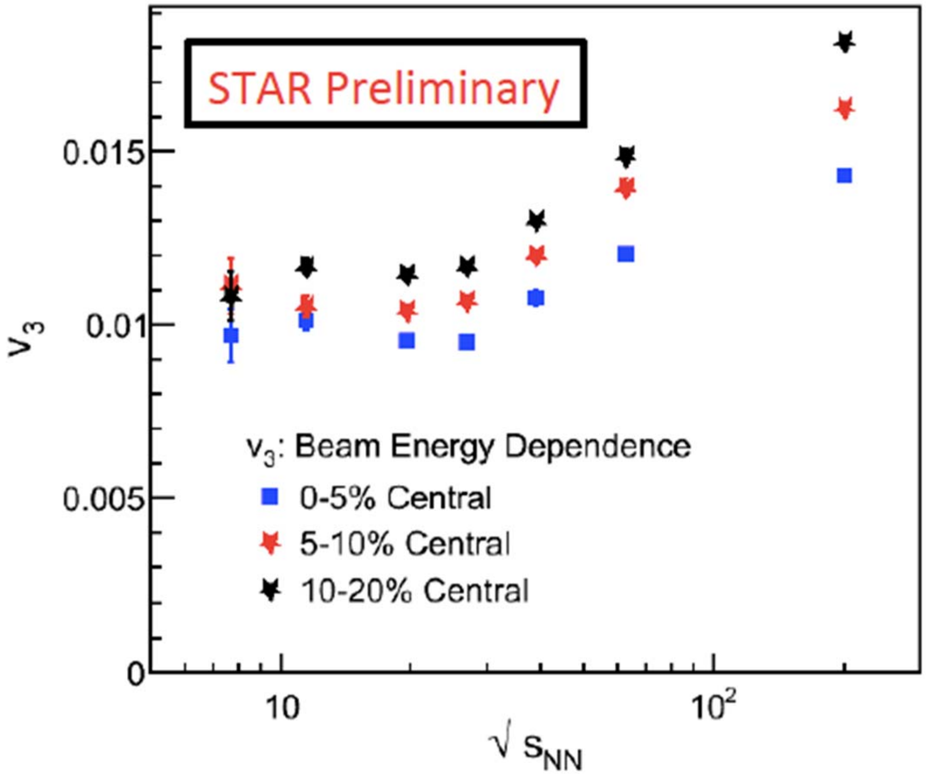


Similar p_T distributions for all v_n for $\sqrt{s_{NN}}$ = 39-200 GeV

Likely numerous things changing that happen to cancel out

v_3 and sensitivity to EoS

Y. Pandit, STAR, Quark Matter 2013

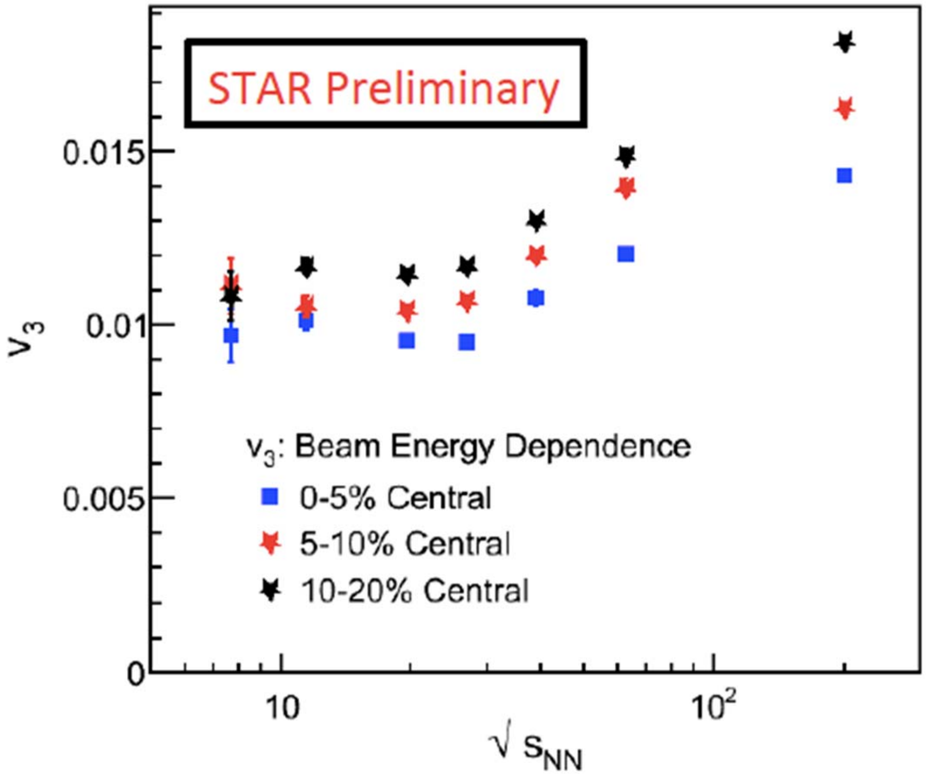


v_3 sizable even at 7.7 GeV

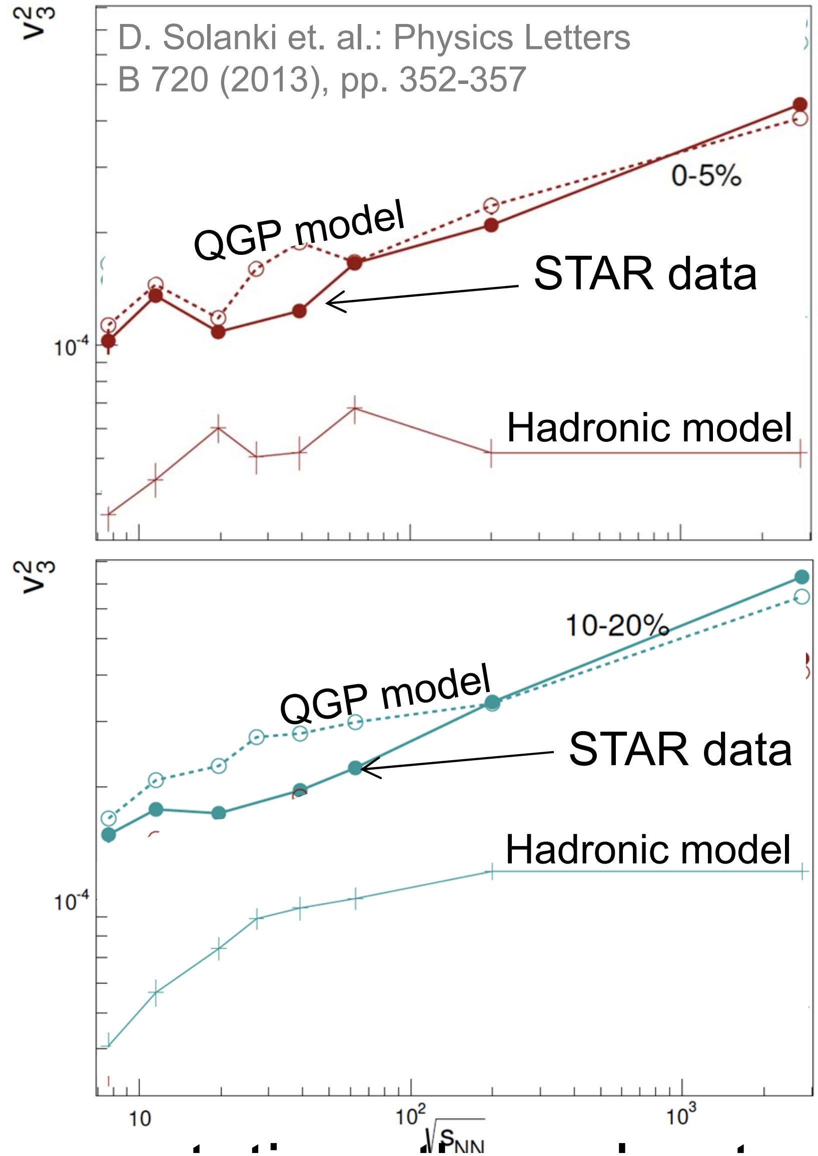
- jet contribution essentially zero

v_3 and sensitivity to EoS

Y. Pandit, STAR, Quark Matter 2013



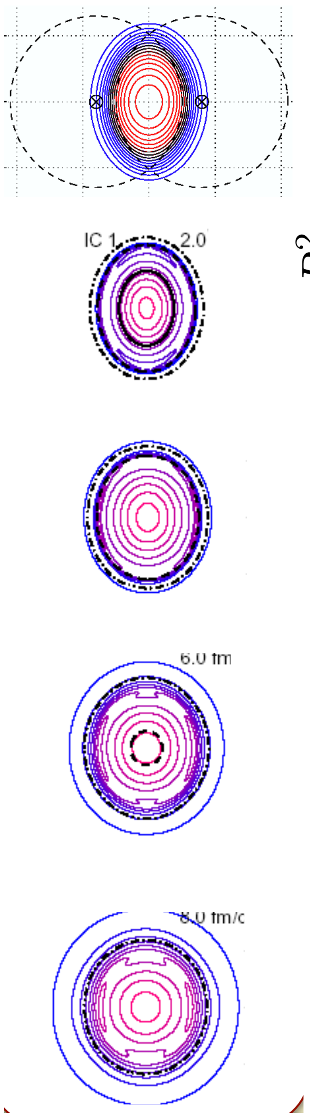
D. Solanki et. al.: Physics Letters B 720 (2013), pp. 352-357

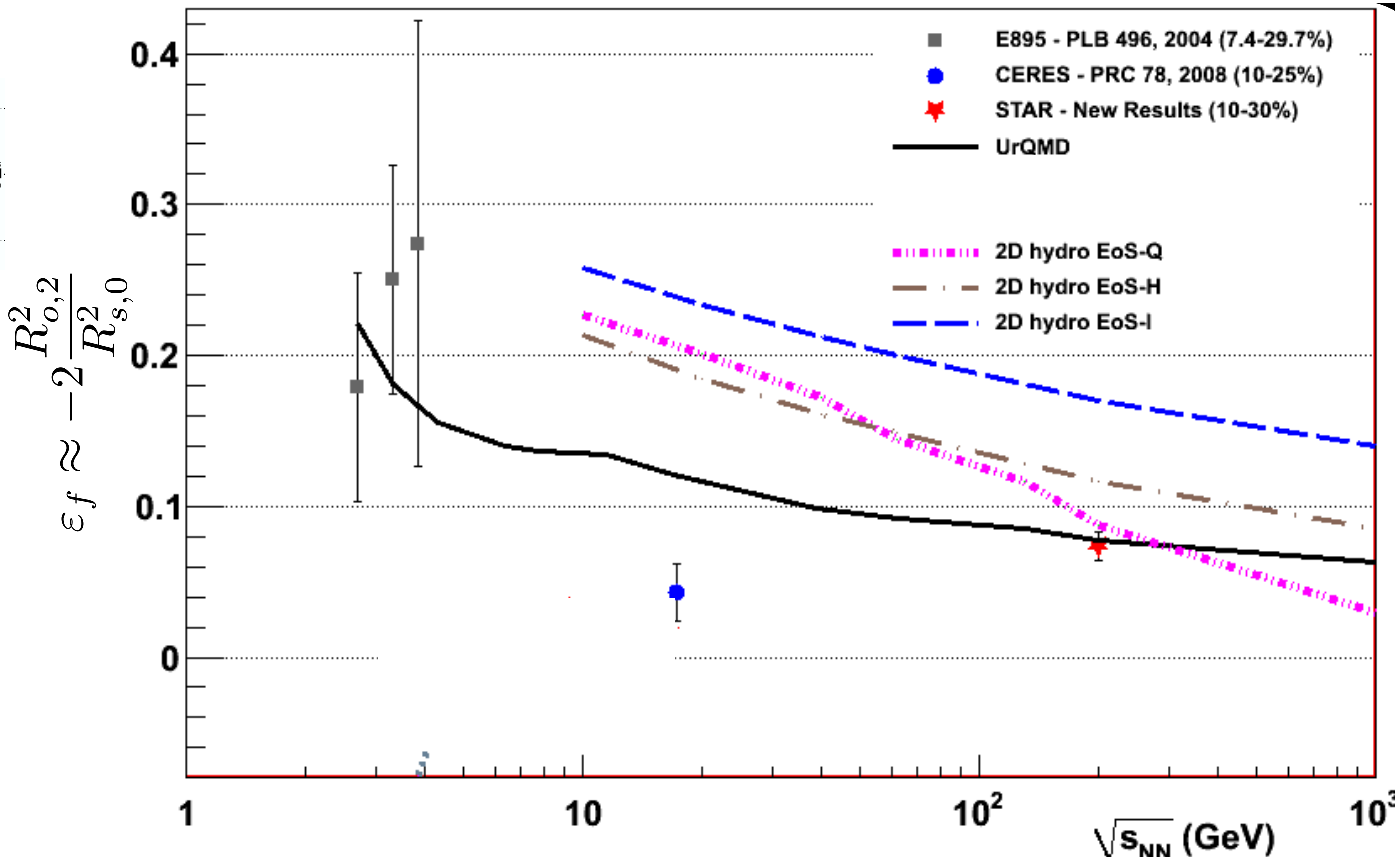


v_3 sizable even at 7.7 GeV
- jet contribution essentially zero

STAR data in reasonable agreement with QGP version of AMPT for all $\sqrt{s_{NN}}$

Pre BES - Azimuthally sensitive HBT





Sensitive to EoS

Naively:

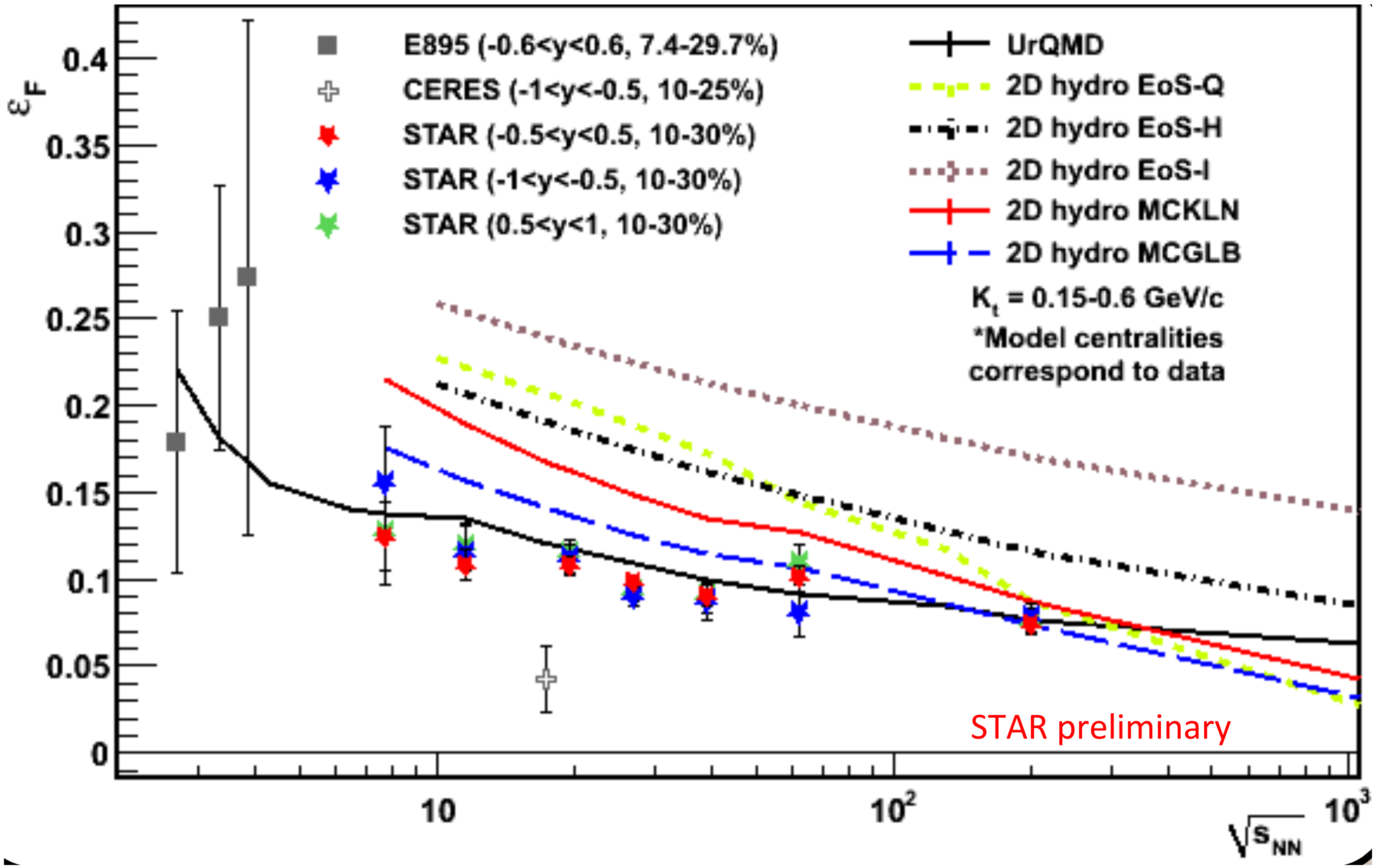
higher $\sqrt{s_{NN}}$ → higher pressure → evolve to smaller ε_f

higher $\sqrt{s_{NN}}$ → longer lifetime → evolve to smaller ε_f

CERES data hint at something interesting

Azimuthal HBT

M.Lisa CPOD

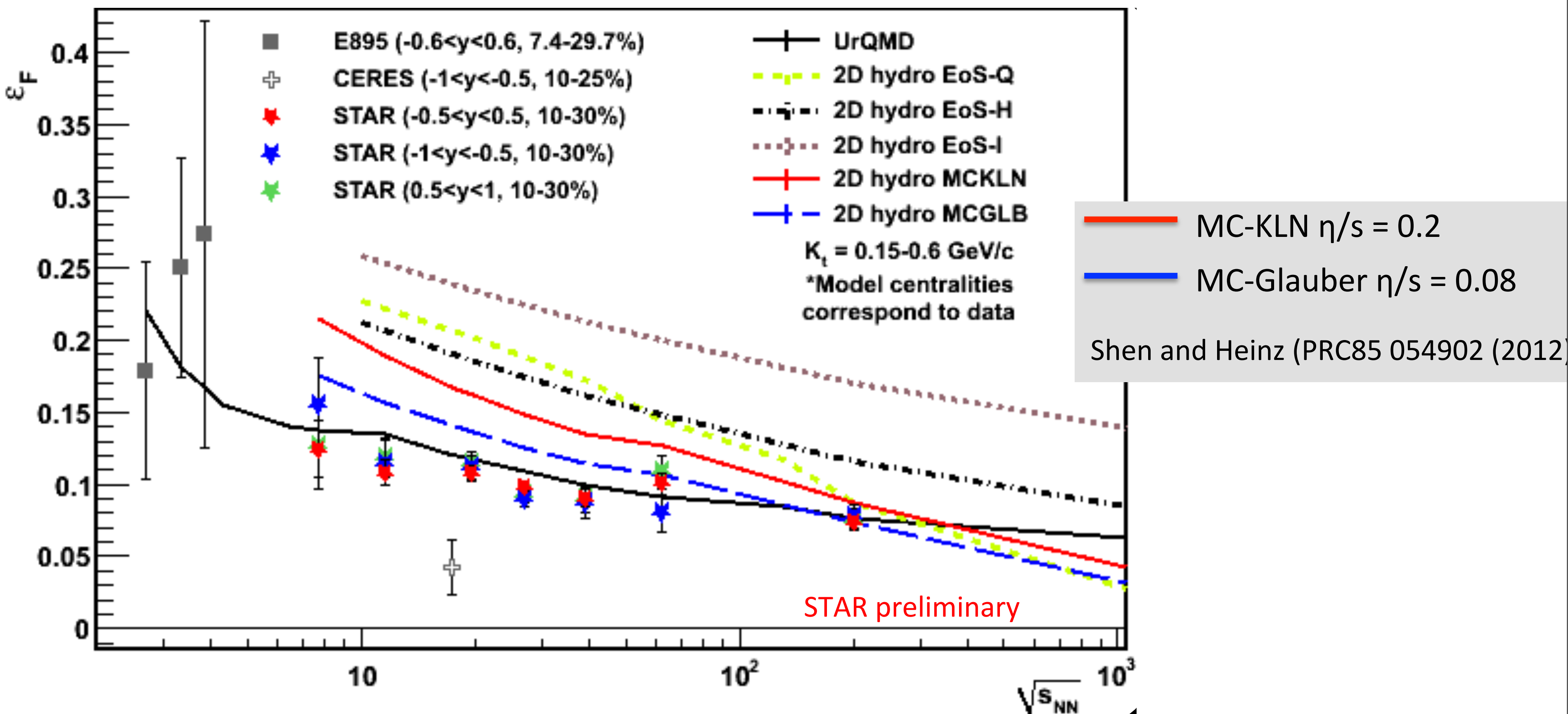


Shallow monotonic decrease for STAR data - even for CERES acceptance

Sensitivity to initial-state/viscosity

Azimuthal HBT

M.Lisa CPOD



Shallow monotonic decrease for STAR data - even for CERES acceptance

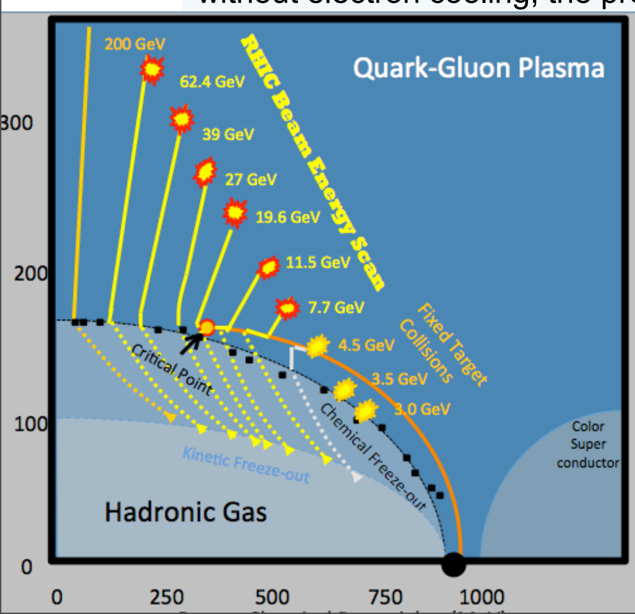
Azimuthal Coordinate space measurement breaks degeneracy from azimuthal momentum space

Sensitivity to initial-state/viscosity

Future prospects - BES-II and fixed target

$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	BES-I	BES-II	Physics Motivation	Weeks**
200	24		**0.5-2** (B)	Heavy flavor hadron v_2 & R_{AA}	
39	112	130 (M)			
27	156	70 (M)			
19.6	206	36 (M)	**400** (M)	LMR di-electron*, net-p κ>5σ	**2**
15	250		**100** (M)	Ω yield, ϕ-meson v_2 (≤ 3GeV/c)	**2**
11.5	316	12 (M)	**120** (M)	net-p κ	**3.5**
7.7	420	5 (M)	**80** (M)	net-p κ	**10**

* Di-electron measurements below 19.6 GeV are not planned
** Estimates are based on electron cooling upgrade currently under development and are approximate without electron cooling, the program would require ~150 weeks



Fixed target experiment at STAR will push down to even lower μ_B

Collider mode $\sqrt{s_{NN}}$ (GeV)	Fixed-target mode $\sqrt{s_{NN}}$ (GeV)	Fixed-target mode μ_B (MeV)
19.6	4.5	585
15	4.0	625
11.5	3.5	670
7.7	3.0	720
5	2.5	775

Conclusions

- I'm in the minority but I think pA BES would be very interesting
- Hopeful can disentangle contributions to initial state via variety of measurements - HBT making a comeback?!?!!
- Lots of puzzles from the BES
  - even if hints for Critical Point and 1st order transitions are not leaping out

The End